EFFECT OF SUBSTRATE AND NUMBER OF COATS ON THERMAL EMITTANCE AND SOLAR REFLECTANCE MEASUREMENTS OF PAINTS

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ABSTRACT

This study investigated the impact of four substrates and the number of paint coats on both solar reflectance and thermal emittance. For the experiments, three types of spray paint (white, silver, and green) coated four substrates: ceramic, fibre cement, aluminium, and sandpaper. The methodology was divided into three main stages: sample preparation and painting, measurement of properties, and result analysis. Solar reflectance was determined using the ASTM E903 standard with a UV-VIS-NIR spectrophotometer, while thermal emittance measures following the ASTM C1371 standard with a portable emissometer. The samples were assessed in their natural (unpainted) state and after applying one, two, and three coats of paint. Results indicated that both the number of paint coats and the substrate type significantly influence these properties. For solar reflectance, the absolute variation from the first to the second coat reached 0.35, and from the second to the third, 0.19. Regarding thermal emittance, the non-metallic substrates painted with white and green showed slight variations (0.01 to 0.03) compared to the unpainted reference. However, significant emittance variations occurred for aluminium substrates painted with silver, with values increasing up to 0.72. These results highlight the importance of considering material combinations and paint coatings in building design to optimize thermal performance.

KEYWORDS: *Solar Reflectance, Thermal Emittance, Paints, Substrates, Buildings.*

I. INTRODUCTION

In the 21st century, the efficient use and reduction of energy consumption have become critical priorities across various sectors. According to the Brazilian National Energy Balance [1], in 2022, the residential, commercial, and public sectors accounted for 51% of Brazil's electricity consumption, with a significant portion used to maintain and control the thermal conditions of buildings. This scenario highlights the importance of characterizing materials to enhance energy efficiency and thermal comfort in buildings.

Solar reflectance and thermal emittance are surface properties that influence the thermal performance of construction materials. Solar reflectance relates to heat transmission, while thermal emittance measures a material's ability to radiate heat from its surface. These properties are highly dependent on factors such as surface composition, roughness, and finishes, significantly influencing building energy efficiency. Consequently, they are increasingly integrated into technical standards and building codes, guiding the selection of materials for facades, roofs, and other building envelope components.

In Brazil, researchers have advanced the understanding of these properties through various studies. For example, [2] analysed the effects of surface roughness on absorptance and emittance, while [3] evaluated how measurement techniques influence thermal emittance results. [4] conducted laboratory analyses of roof tiles. [5] investigated the impact of natural aging on the optical and thermal properties of surfaces. [6] presents a study on the variation in the solar reflectance of fiber-cement roof tiles, where solar reflectance was evaluated for newly painted roofs and also for old roofs with different ages to compare their degradation over the years. The study developed by [7] shows the synthesis and characterization of pigments based on lanthanum-doped bismuth ferrite, a more environmentally friendly pigment, with high reflectance in the near infrared. [8] examined the energy performance and durability of thermochromic coatings applied to ceramic and fiber cement roof tiles in two climatically different Brazilian cities. Also, [9] presents a method to evaluate the thermal and economic benefits of cool roofs (high solar reflectance) in unconditioned buildings. These contributions emphasize the need for in-depth assessments of these properties to optimize building design and energy performance.

Other researchers around the world have explored the influence of surface properties on energy performance, emphasizing the role of surface roughness, material composition, and finishing in modifying thermal emittance and solar reflectance. More than five decades ago, [10] found that roughened aluminium surfaces exhibit increased emittance, reinforcing the significance of surface modifications in thermal performance. The accuracy of measurement techniques also plays a crucial role in material characterization. [11] compared different methods for assessing thermal emittance and found significant variations depending on the measurement approach, underscoring the need for standardized procedures. Furthermore, [12] provided guidelines for thermal emission measurements, addressing challenges in accurately characterizing emissivity at varying temperatures. [13] demonstrated how surface roughness affects light absorption in metallic and dielectric films, highlighting the importance of microstructural characteristics in energy efficiency. These studies align with findings from Brazilian research and highlight the need for precise material characterization to optimize energy performance in buildings.

Understanding how surface properties, measurement techniques, and material composition influence solar reflectance and thermal emittance is essential for improving building envelope design, reducing cooling loads, and enhancing overall energy efficiency. Paints play an important role in this context as they are widely used for protection and decoration on facades, roofs, and floors. Architectural paints represent a significant share of Brazil's paint market and are available in various colours and compositions [14]. According to a study by [15], the architectural coatings segment accounted for approximately 55% of the total paint and coatings market in Brazil, reflecting the ongoing importance of this sector in the country's paint industry. These colours and compositions variations can significantly affect properties such as solar reflectance and thermal emittance, influencing thermal loads and air conditioning costs in buildings.

This study examines how the type of substrate and the number of paint coats affect solar reflectance and thermal emittance values. By analysing these variables, it contributes to a deeper understanding of the thermal performance of paints, supporting their optimized use in architectural applications and enhancing the energy efficiency of buildings.

The text of this article is structured into five sections. The Introduction provides context for the research problem, its importance, and the research objectives. The Materials and methods section details the processes used to develop the study. The Results and discussions section presents results of substrate effect and paints coats number on thermal emittance and solar reflectance measurements, including graphs and detailed analyses. The Limitations and future works section presents limitations identified and some suggestions for future work. Finally, the Conclusions summarize the principal outcomes, practical implications and recommendations.

II. MATERIALS AND METHODS

The development of this work followed a method organized into three main phases: sample painting, measurement of thermal emittance and solar reflectance properties, and analysis of the results.

2.1. Selection of Paints and Substrates

For the tests, three types of commercial general-purpose spray paints were selected (in white, silver, and green colours), as illustrated in Figure 1. These paints were applied on four different substrates (Table 1).

Figure 1: Spray paints used for sample painting

Table 1 – Substrates analysed

Substrates	Materials	Dimensions	Thickness
Ceramic	Ceramic tablet	7x7 cm	6.0 mm
Aluminium	Aluminium sheet	9x9 cm	0.7 mm
Fibre cement	Fibre cement tablet	9x9 cm	8.0 mm
Sandpaper	40 grit sandpaper	9x9 cm	1.4 mm

Commonly used in civil construction, materials such as ceramics and fibre cement serve in roofing, cladding, and sealing elements. Aluminium, a metallic material, is widely used in civil construction for applications such as window frames and facade cladding. Sandpaper, specifically iron sandpaper, selected as a substrate to simulate the rough texture of mortar plaster on walls.

2.2. Paint Application Method

The paint application method involved using parallel stripe movements, as illustrated in Figure 2, maintaining a consistent distance of 20 cm throughout the process. Samples were prepared with one coat (1C), two coats (2C), and three coats (3C) for each substrate analysed. Each layer of paint dried naturally for a minimum of 24 hours between applications.

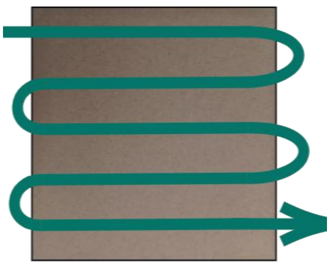


Figure 2: Painting method employed

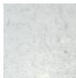
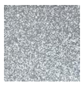
2.3. Sample Painting

Table 2 displays the reference samples of the previously selected substrates (ceramic, fibre cement, aluminium, and sandpaper), and Table 3 shows the samples of the four types of substrates after the application of each coat for each of the three selected colours. In total, 40 samples were evaluated (4 unpainted and 36 painted).

Table 2 - Reference samples (unpainted)

Sample	Ceramic	Fibre cement	Aluminium	Sandpaper
Unpainted				

Table 3 – Samples after application of each coat (C) of paint

Colour \ Number of coats		1C	2C	3C
Ceramic	White (W)			
	Silver (S)			
	Green (G)			
Fibre cement	White (W)			
	Silver (S)			
	Green (G)			
Aluminium	White (W)			
	Silver (S)			
	Green (G)			
Sandpaper	White (W)			
	Silver (S)			
	Green (G)			

2.4. Emittance Measurement

Measurements were performed on the samples in their initial condition (without paint) and after applying each coat of paint, allowing for the drying 24h interval between each layer.

According to ASTM C1371 [16], the use of a portable emissometer is recommended to evaluate thermal emittance at near room temperature. Figure 3 shows D&S emissometer, model AE1 (with an adapter). This emissometer has an output voltage that maintains a linear relationship with the emittance. During the testing procedure, two calibration standards were employed one with high emittance (ε = 0.88) and one with low emittance (ε = 0.06). The thermal emittance evaluation begins with the detector warming up, and after stabilization, calibration carried out using the mentioned high and low emittance standards. Calibration involves measurements lasting 90 seconds, alternating between each standard.

Figure 3: Portable emissometer components:
1) Detector; 2) Multimeter; 3) Calibration Standards

Regarding measurement uncertainty, ASTM 1371 states that statistical analyses were performed on the results of measurements (steel and copper samples) paired by the emissometer and absolute techniques. The analyses did not show any statistically significant difference (at the 5% significance level) between the mean values obtained with the emissometer and the absolute techniques. The largest absolute deviation reported in the evaluation described in the standard is 0.019 (~0.02), which can be considered as the measurement uncertainty.

2.5. Solar Reflectance Measurement

The ASTM E903 [17] standard recommends using a spectrophotometer with an integrating sphere for reflectance measurement. In this study, a spectrophotometer with a 150 mm integrating sphere was employed (Figure 4). The use of this equipment is particularly suitable for measurements on flat and homogeneous surfaces. The ASTM E903 standard specifies that measurements should cover the wavelength range (λ) from 300 to 2500 nm, with readings at 5 nm intervals. For the calculation of solar reflectance it is also considered the reference spectrum given by ASTM G173 [18].

Figure 4: Spectrophotometer PerkinElmer Lambda 1050 model

Regarding measurement uncertainty, the ASTM E903 standard highlights those results from interlaboratory comparison studies that report an uncertainty of 0.02 units, or approximately 2% when applying the measurement method.

III. Results And Discussions

3.1. Thermal Emittance Evaluation Results

The results for the thermal emittance values of each sample presented below.

3.1.1. Ceramic Substrate

In the white and green paints, all values exceeded the reference (0.84) (Figure 5). In all coats of these two paints, the increase in emittance was in the range of 0.02 to 0.05, with the greatest variation occurring in the green paint with three coats. In the case of the silver paint, the emittance values decreased in all coats. Due to this paint application, the emittance reduction ranged from 0.24 to 0.61. The greatest variation between coats occurred from the first (0.60) to the second (0.27) coat of paint (a reduction of 55%).

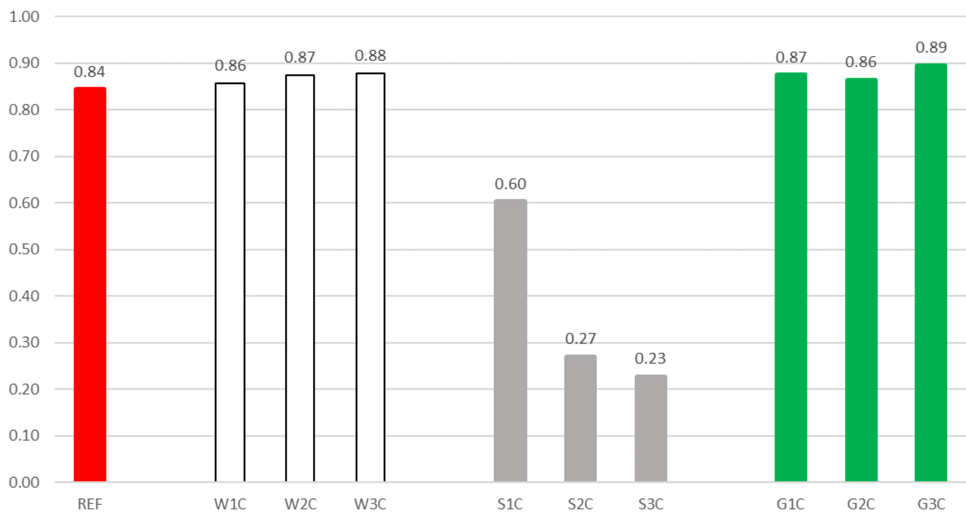


Figure 5: Average emittance of ceramic samples after each coat.

3.1.2. Fibre Cement Substrate

In the white and green paints, most of the emittance values exceeded the reference (0.89). The emittance variation in the coats of these paints ranged from -0.02 to 0.03, with the greatest variation occurring in the green paint with three coats (Figure 6). In the silver paint, the greatest variation between coats occurred, representing a 66% reduction in emittance, from the first coat (0.72) to the second coat (0.24). In all colours analysed, the average emittance values showed a decrease when the second coat was applied, followed by an increase in the third coat.

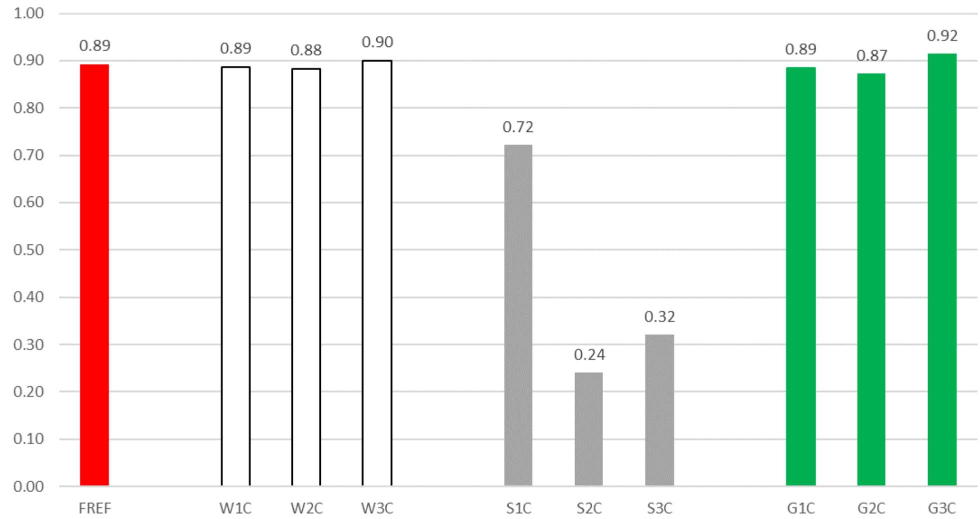


Figure 6: Average emittance of fibre cement samples after each coat.

3.1.3. Aluminium Substrate

In the aluminium case, all values exceeded the reference (0.06). The increase in emittance ranged from 0.12 to 0.72, with the greatest variation compared to the reference occurring with the white paint after three coats (0.78). The increase in emittance from the reference to the first coat of white paint (0.38) represented a 533% difference from the initial value. Except for the increase from the first (0.18) to the second (0.20) coat of silver paint, all samples showed a percentage increase between coats of more than 10%. Figure 7 presents the emittance values for the aluminium samples after each coat of paint.

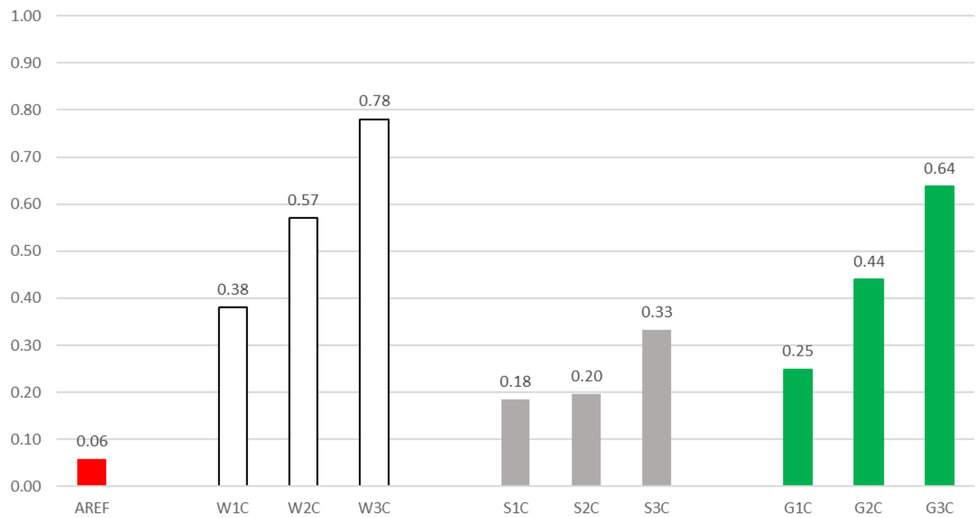


Figure 7: Average emittance of aluminium samples after each coat.

3.1.4. Sandpaper Substrate

Similar to ceramic and fibre cement, the emittance values for white and green paints remained very close to the reference standard (Figure 8). The emittance variation for these two paints compared to the reference (0.93) ranged from -0.01 to 0.01. For the silver paint, there were significant variations in emittance after the application of each coat: a 24% reduction after the first coat (0.71), another reduction of 45% from the first to the second coat (0.39), and finally an increase of 82% from the second to the third coat (0.71). For all colours, the average emittance values showed a decrease with the second coat, followed by an increase with the third coat.

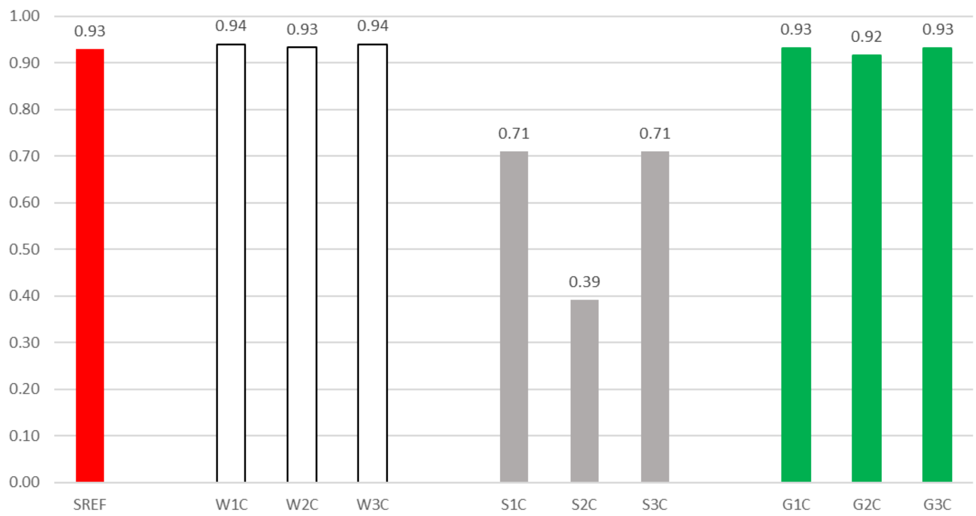


Figure 8: Average emittance of sandpaper samples after each coat.

3.2. Solar Reflectance Evaluation Results

The results for the solar reflectance values of each sample presented below.

3.2.1. Ceramic Substrate

Figures 9, 10 and 11 presents the spectral reflectance curves of the ceramic samples after the application of each coat of paint, along with the reference curve of the ceramic (CerREF) without coating. The curves show a significant increase in reflectance with each additional coat of white paint (Figure 9). This increase in reflectance begins in the IR region (2000 nm), reaches its peak in the VIS region at around 400 nm, and then drops sharply in the UV range. As can also be observed, the reflectance curves for the silver paint (Figure 10) displayed a more horizontal pattern. For the first coat, the curve remained approximately in the 50–60% range, while for the second coat, it ranged between 70% and 90%. By the third coat, the reflectance gain was minimal, and the curve practically maintained the same shape across the entire range. The shape of the curves for the green paint (Figure 11) for all three coats was very similar to the reference across almost the entire IR range (900–2500 nm). Below 900 nm, the curves of the three painted samples significantly drop, remaining below 10% across almost the entire VIS and UV range.

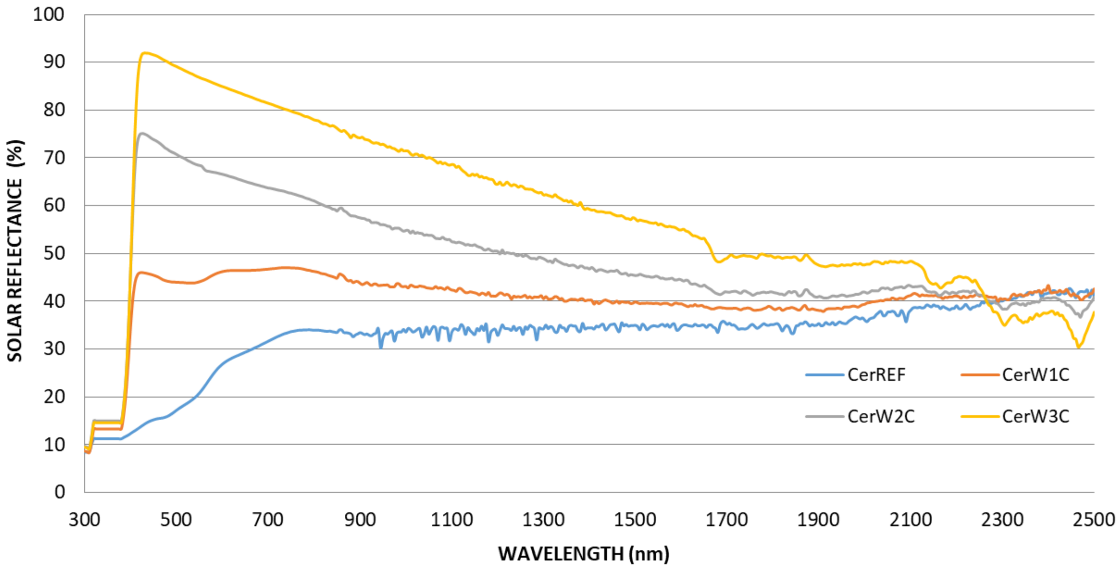


Figure 9: Reflectance spectral curves of ceramic samples after each coat of white paint.

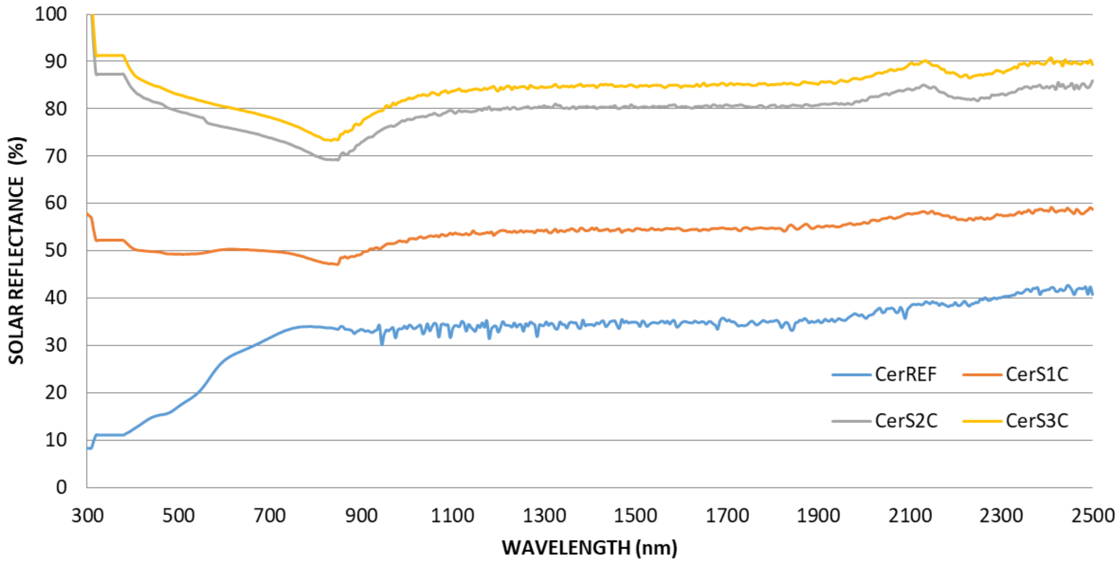


Figure 10: Reflectance spectral curves of ceramic samples after each coat of silver paint.

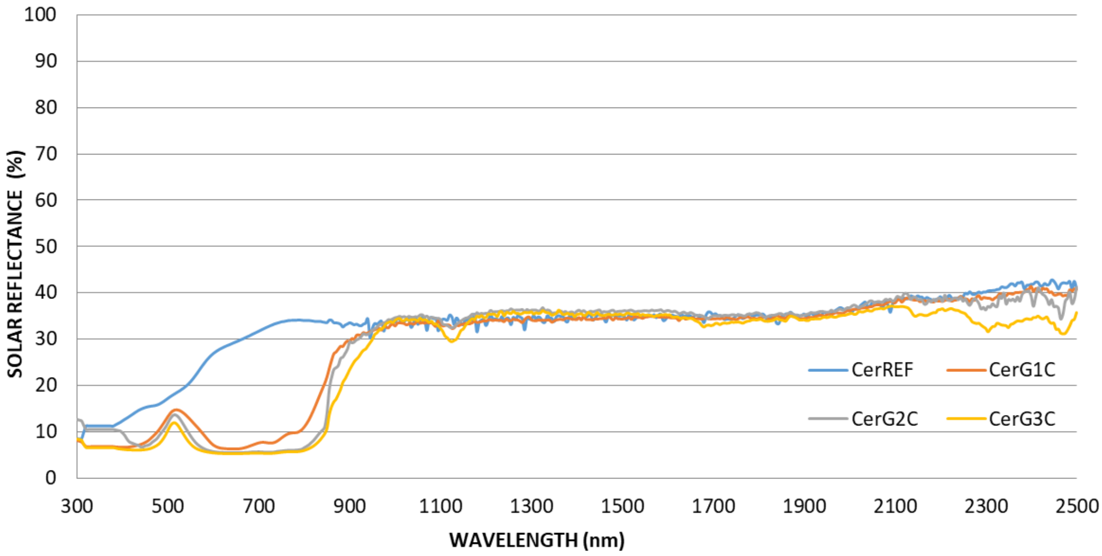


Figure 11: Reflectance spectral curves of ceramic samples after each coat of green paint.

Table 6 presents the absolute solar reflectance values of the ceramic samples in the unpainted condition (CerREF) and for 1C, 2C, and 3C. Figure 12 shows the percentage change between the reference and the first coat, as well as between successive coats. In the case of the white paint, the percentage increase per coat was around 55%.

In Figure 12, the first coat provided a 35% reduction for green paint, while in the following coats the reduction reached a maximum of 5%. The silver colour showed a variation of over 80% between the reference and the first and from the first to the second coat, and a less significant increase from the second to the third coat (15%).

Table 6 – Solar reflectance of ceramic samples

Sample	**Solar Reflectance**			
	Unpainted	*1C*	*2C*	*3C*
Reference	0.277			
White		0.429	0.586	0.738
Silver		0.508	0.776	0.816
Green		0.179	0.170	0.155

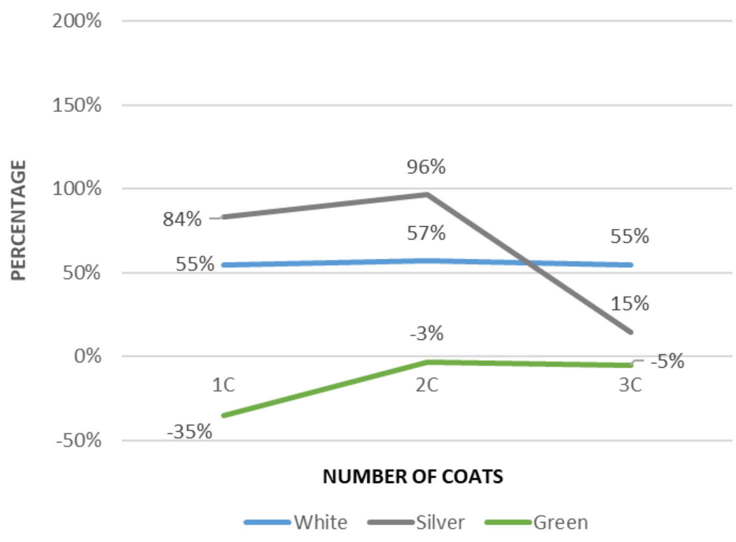


Figure 12: Solar reflectance variation on ceramic samples after each coat.

3.2.2. Fibre Cement Substrate

Figures 13, 14 and 15 shows the reflectance spectral curves of the fibre cement samples after applying each coat of paint. We present the reference curve for unfinished fibre cement (FibREF). Where the reflectance values range from 30 to 40% in the UV, VIS, and IR up to wavelengths close to 1900 nm. From this point the reflectance drops to approximately 20% (lambda = 2500 nm).

As with the ceramic substrate, Figure 13 shows that the reflectance spectral curves have a significant increase with the application of each additional coat of white paint. Looking from the end of the curve, this elevation begins at length 2500 nm (in the IR region), reaching its peak in the visible region and falling sharply in the UV range. In Figure 14, the reflectance spectral curves for the silver paint had a horizontal behaviour mainly in the IR range, from 1000 to 2500 nm. In the first coat, the curve remains in the range of 40 to 50%, presenting a not very pronounced variation in relation to the reference. With the addition of the second coat of paint, the reflectance changes significantly, jumping to the 70 to 90% range. However, with the application of the third coat there was practically no change in values, with an overlap with the curve of the second coat.

Again, even with the change to the fibre cement substrate, the shape of the reflectance spectral curves for the green paint (Figure 15) in the three coats remained very close to the reference throughout almost the entire IV range. Throughout the VIS and UV range, the curves of the three painted samples remained below 10%, except for the occurrence of a peak around the length of 500 nm.

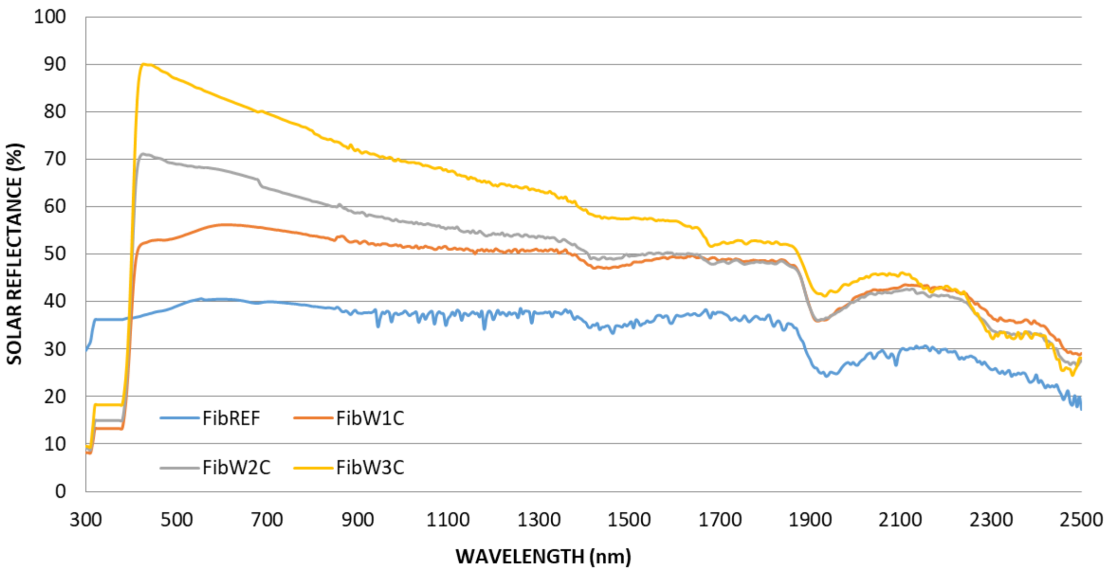


Figure 13: Reflectance spectral curves of fibre cement samples after each coat of white paint.

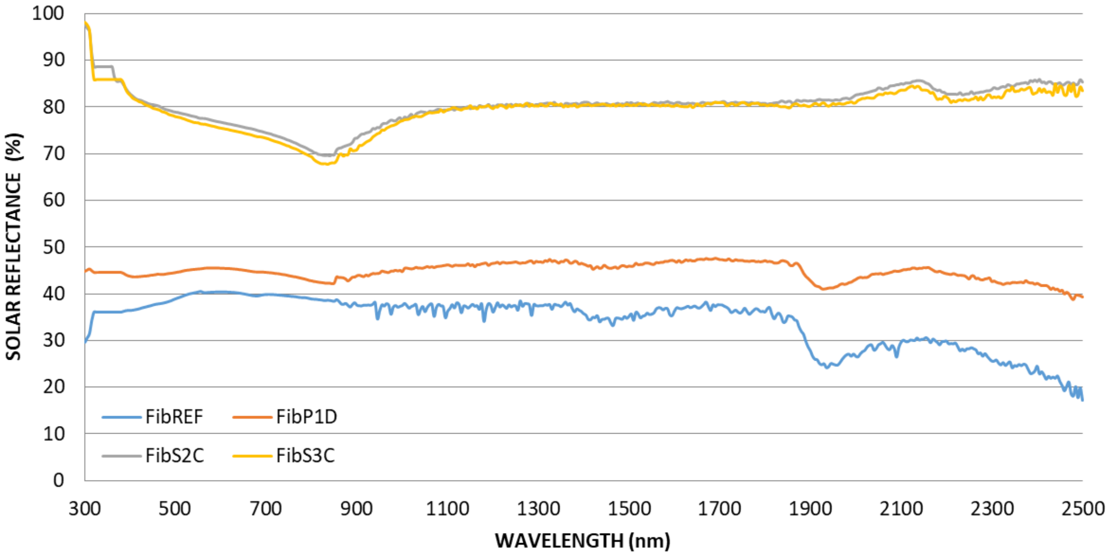


Figure 14: Reflectance spectral curves of fibre cement samples after each coat of silver paint.

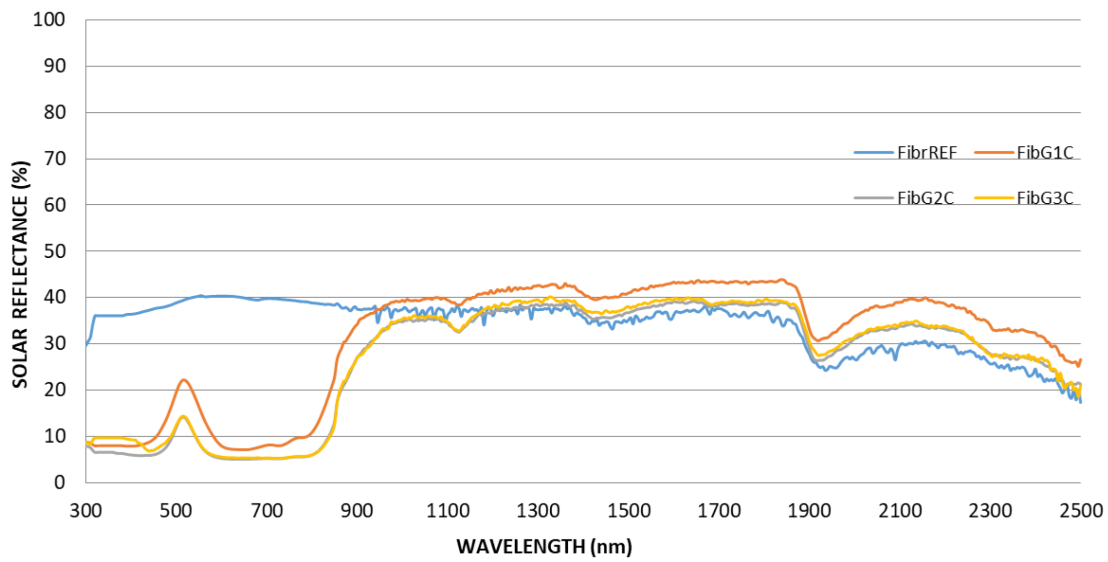


Figure 15: Reflectance spectral curves of fibre cement samples after each coat of green paint.

Table 7 presents the absolute solar reflectance values of fibre cement samples in the unpainted condition (FibREF) for 1C, 2C and 3C. The variation graph (Figure 16) shows the percentage in relation to the reference and between coats. It is possible to observe that the application of the first coat in the case of white and silver paint increased the reflectance in relation to the original substrate. In the case of green, there was a reduction. Evaluating the reflectance between coats, the greatest variation in white paint occurred with the third coat of paint (34%). For the silver colour, the greatest increase (86%) occurred with the application of the second coat. In addition, for the green colour, there was no significant change after the third coat (-3%).

Table 7 – Solar reflectance of fibre cement samples

Sample	**Solar Reflectance**			
	Unpainted	*1C*	*2C*	*3C*
Reference	0.381			
White		0.509	0.594	0.725
Silver		0.447	0.776	0.766
Green		0.211	0.165	0.170

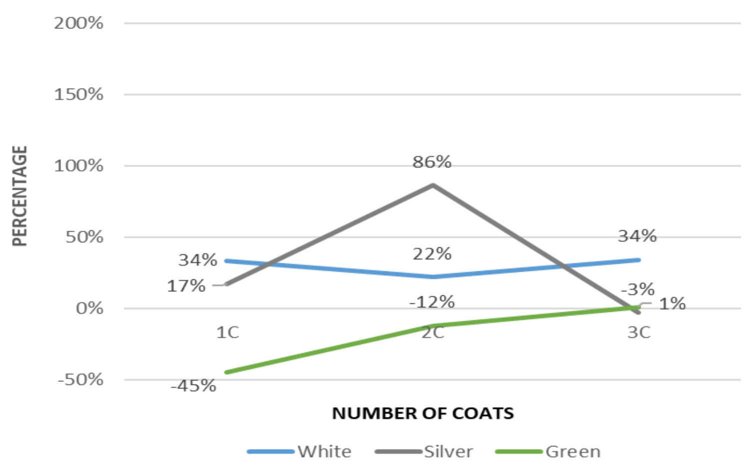


Figure 16: Variation of solar reflectance on fibre cement samples after each coat.

3.2.3. Aluminium Substrate

The reflectance spectral curves of the aluminium samples for the colours white, silver, and green in each of the coats (1C, 2C, and 3C) are presented in Figures 17, 18 and 19, which also shows the unpainted reference curve (AluREF), which has reflectance values above 80% in practically the entire range of the evaluated spectrum.

Figure 17 shows that at the end of the IR range (1700 to 2500 nm) the spectral reflectance values for the white paint show a reduction as the second and third coats are applied. Around the length 1200 to 1300 nm, there is a reversal in this trend. From then on, the reflectance values increase with each coat throughout the VIS range, reaching a peak at approximately 400 nm, and having an abrupt drop in the UV range.

For the silver paint (Figure 18), the spectral curves of the three coats showed the same shape as the reference curve of the unpainted substrate (AluREF). The spectral reflectance values for each of the coats (1C, 2C, and 3C) were observed as very close to each other, but below the curve of the unpainted substrate. Overall, the curves of the painted samples had reflectance values approximately between 70 and 90% throughout the entire VIS and IR range. In the UV range, values remained above 80%.

As with the other colours, the behaviour of the green paint sample curves (Figure 19) was similar to each other throughout practically the entire range analysed. In some parts of the spectrum, it was possible to observe that the reflectance decreases with each new coat, for example in the range between 900 and 1700 nm. It is worth noting that in most of the IR range (1100 to 2500 nm), the result for the three coats remains above 50%. Below 800 nm, the reflectance value remains close to 10%, except around the 500 nm length where a peak occurs in the three coats. It is also possible to identify that in the UV and VIS range the curves of the second and third coats practically overlap.

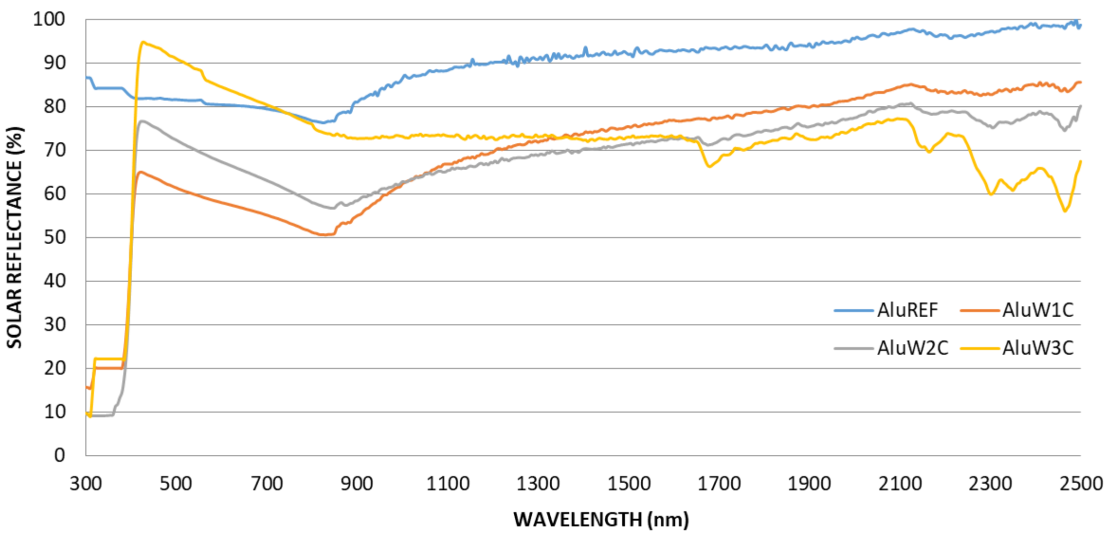


Figure 17: Reflectance spectral curves of aluminium samples after each coat of white paint.

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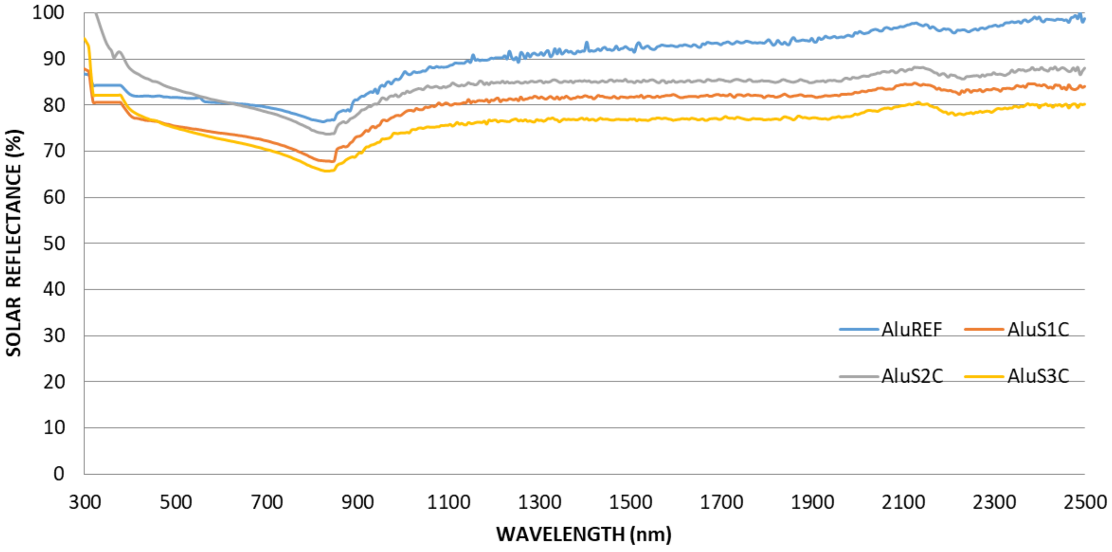

Figure 18: Reflectance spectral curves of aluminium samples after each coat of silver paint.

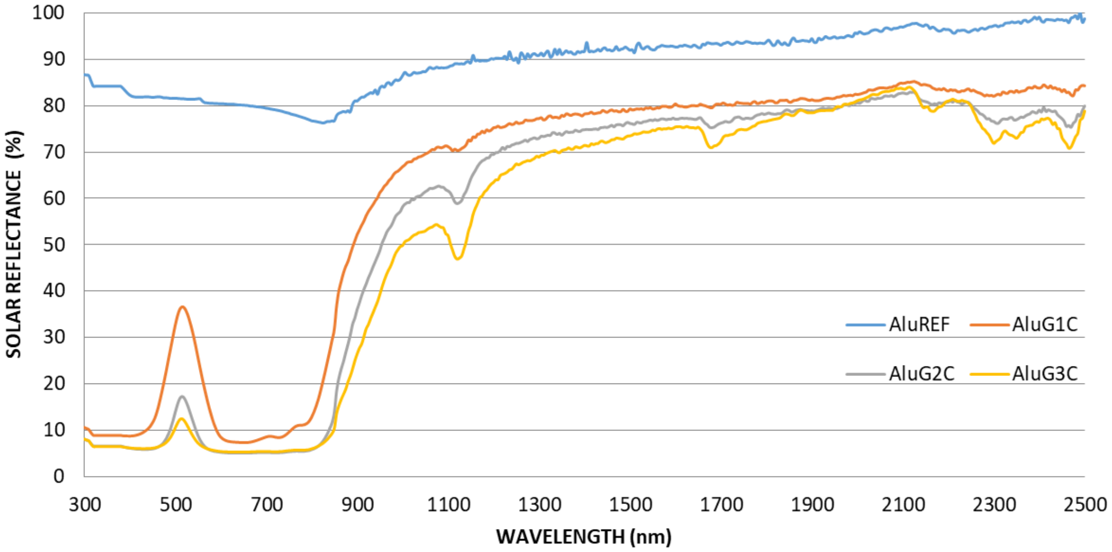

Figure 19: Reflectance spectral curves of aluminium samples after each coat of green paint.

The absolute solar reflectance values of the aluminium samples are present in Table 8. The variation graph (Figure 20) shows the percentage change in relation to the reference and between coats. For white, it is possible to note that there was a 28% reduction in the original reflectance of the substrate with the application of the first coat and subsequently an increase with the application of each subsequent coat.

In Figure 20, the application of the first coat reduced the reflectance value by 9% for silver paint, followed by an increase after applying the second coat (returning almost to the substrate's original value) and a new reduction in the third coat. As for the green colour, there was a reduction in reflectance with the application of each coat, being more pronounced in the first coat (-59%) and varying very slightly from the second to the third coat (-3%).

Table 8 – Solar reflectance of aluminium samples

Sample	Solar Reflectance			
	Unpainted	*1C*	*2C*	*3C*
Reference	0.833			
White		0.596	0.643	0.771
Silver		0.758	0.821	0.737
Green		0.345	0.266	0.240

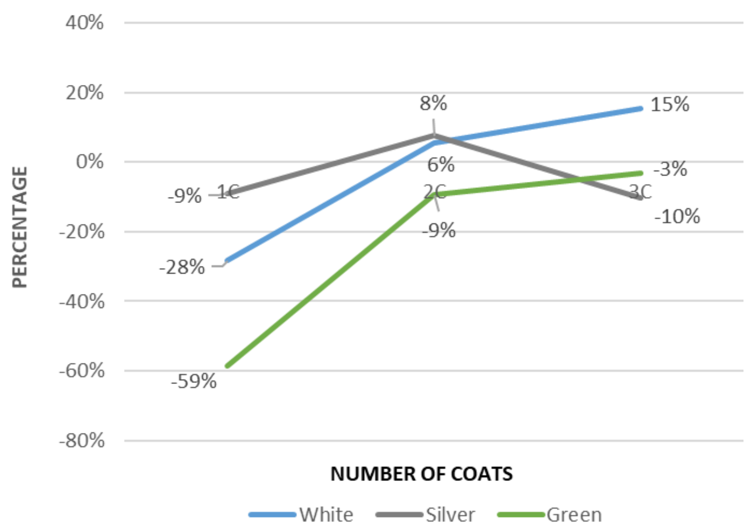

Figure 20: Variation of solar reflectance on aluminium samples after each coat.

3.2.4. Sandpaper Substrate

Figures 21, 22 and 23 shows the reflectance spectral curves for iron sandpaper in white, silver, and green colours for 1C, 2C and 3C. The reference curve (LixREF) was almost a straight line with values less than 10% throughout the entire analysed spectrum.

The white colour graph (Figure 21) shows the increase in reflectance with each new coat from the end of the range (2500 nm) to a peak approximately at 400 nm and a sudden drop in the UV range.

Similar to what happened on other substrates, the silver paint (Figure 22) also presents a more horizontal alignment characteristic across the entire spectrum. For the first coat, the curve was in the range of 30 to 40%. The reflectance values in the second and third coats were very similar, remaining mostly in the range of 60 to 80%. In the case of the green colour (Figure 23) applied to the sandpaper substrate, it is possible to notice that all values remained within a narrow range between 4 and 10%. There is practically an overlap between the curves, with a slight increase in reflectance after applying the third coat.

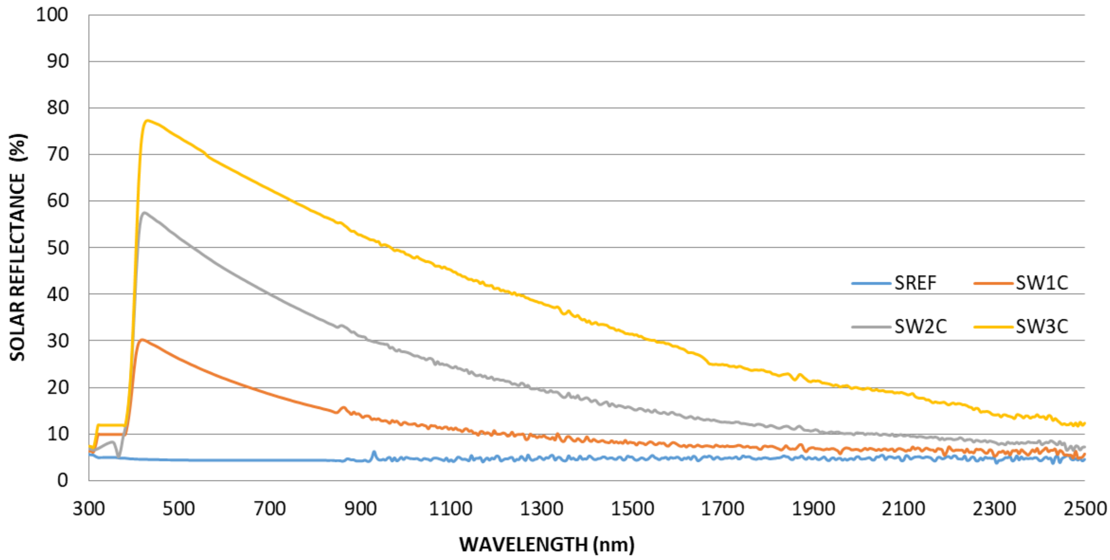

Figure 21: Reflectance spectral curves of sandpaper samples after each coat of white paint.

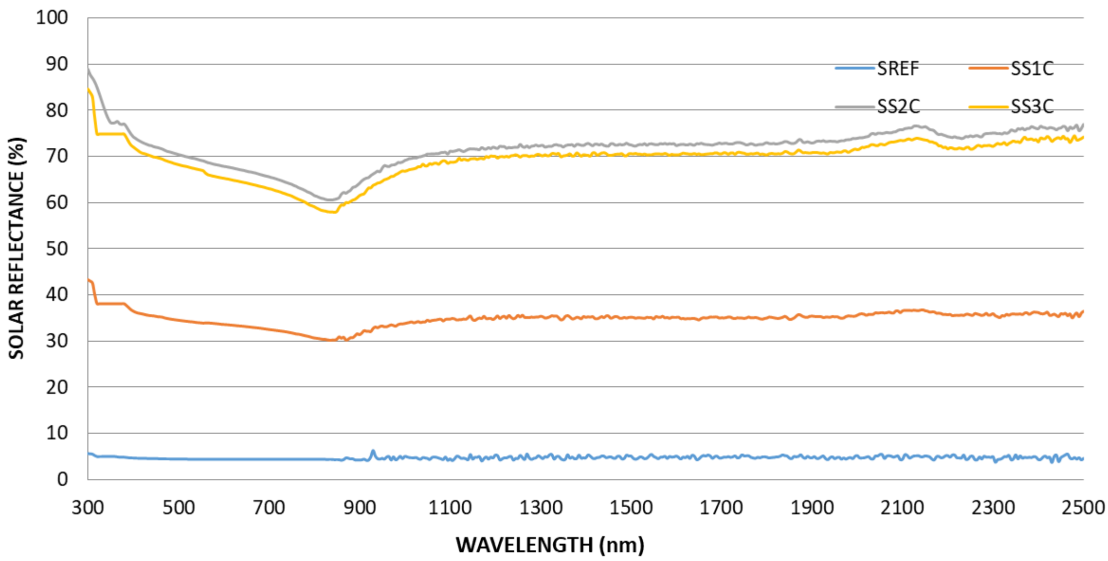

Figure 22: Reflectance spectral curves of sandpaper samples after each coat of silver paint.

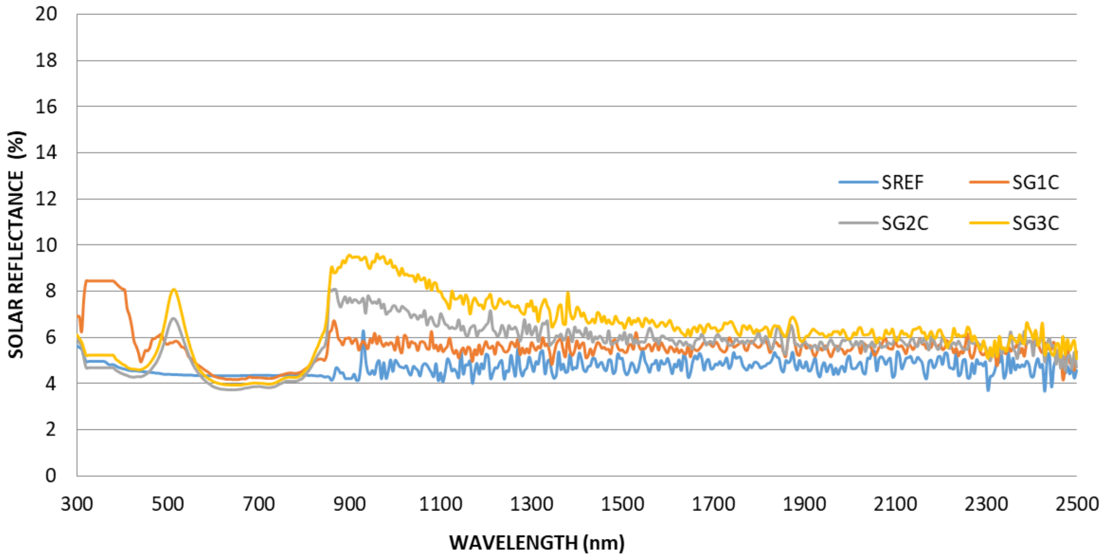

Figure 23: Reflectance spectral curves of sandpaper samples after each coat of green paint.

Table 9 summarises the absolute total reflectance values for each sample condition analysed on the sandpaper substrate.

The variation graph (Figure 24) shows the percentage change in relation to the reference and between coats. Considering that the reflectance value of the unpainted substrate is very low (0.045), the gains with the first coat were very significant for white and silver paint (286 and 653%, respectively).

In Figure 24, the increase in reflectance for white and silver was also high (103% in both) in the second coat, and only white paint had a further increase (55%) in the third coat. For green paint, the biggest increases occurred in the first and third coats (20 and 13%, respectively), however, in absolute terms the positive variation was slight, just 0.015 with three coats.

Table 9 – Solar reflectance of sandpaper samples

Sample	**Solar Reflectance**			
	Unpainted	*1C*	*2C*	*3C*
Reference	0.045			
White		0.174	0.354	0.549
Silver		0.339	0.689	0.665
Green		0.054	0.053	0.060

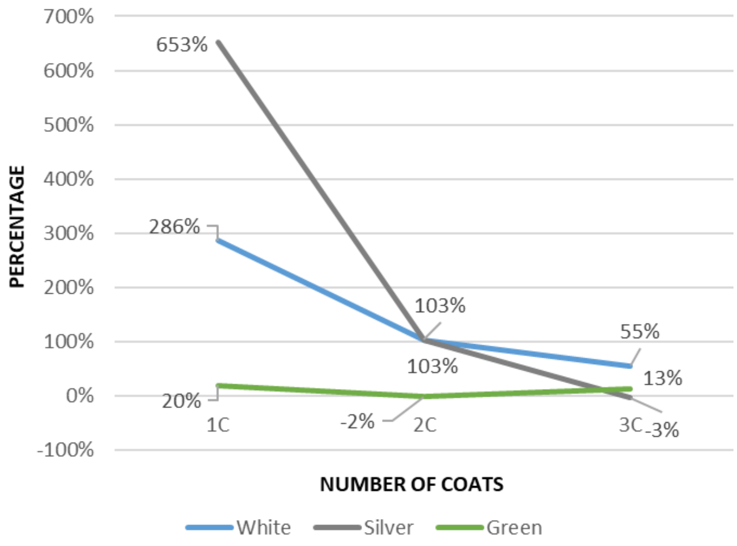

Figure 24: Variation of solar reflectance on sandpaper samples after each coat.

3.3. Results Analysis

For an analysis of the effect of the substrate on thermal emittance and solar reflectance, the study considered the samples with the same colour and three coats (the condition with the best paint coverage).

The aluminium substrate, a metallic material, originally has a smooth and polished surface with low emittance (0.06) in its natural condition. The lowest emittance value (0.78) was observed on this substrate after applying three coats of white, compared to the other substrates of the same colour. Regarding the results of the non-metallic substrates, the variation was at least 0.10, which can be considered a significant difference.

In the non-metallic substrates (ceramic, fibre cement, and sandpaper), a variation in emittance was observed among the samples with three coats of white paint of at most 0.06 (0.88 to 0.94). The fibre cement and ceramic substrates, which have a similar surface finish, presented very close emittance values (0.02) after the application of the third coat of paint. The ASTM C1371 standard determines that for this method, the total hemispherical emittance has an uncertainty range of 0.02 units. Therefore, it is not possible to state that the number of coats causes a significant change in emittance for these substrates (ceramic, sandpaper, and fibre cement) and these colours (white and green) since the variation is within the uncertainty range.

Iron sandpaper was used as a substrate to represent a surface with greater roughness. This surface showed the smallest variation in emittance in relation to its reference, due to the increasing number of coats when compared to the other substrates. This variation was only 0.01. Thus, it is not possible to state that the variation in coats of this paint caused a significant change in the emittance value on this substrate.

In all cases, the substrate showed an influence on the emittance result. Considering the application of three coats of white paint, the substrate originally with low emittance (aluminium) provided a lower emittance value (0.78) for the paint when compared to a high emittance substrate, as was the case with sandpaper, where the emittance with the application of the same paint (white) reached 0.93.

For the application of silver with three coats, the high emittance substrates (ceramic, fibre cement, and sandpaper) showed significant reductions from the reference values of each substrate. The greatest variation after three coats of silver paint occurred in the ceramic substrate, a reduction of 0.61, representing 72% of the initial emittance value for this substrate. In the aluminium substrate, the behaviour differed from the others after applying three coats of paint as the emittance increased by 0.27, indicating 4.5 times the initial emittance value of the substrate. Although there was a reduction in the emittance value from the reference to the third coat of silver paint on the iron sandpaper substrate, there was an increase of 0.32 from the second to the third coat.

In the case of the green colour with three coats, the effect of the substrates on emittance was very similar to that already discussed for white. It was observed that the variation in the emittance result for the other substrates was significantly higher only for the aluminium substrate. For the white paint, this variation in relation to the non-metallic substrates had been at least 0.10, but now for the green, it reached at least 0.25 after three coats. This difference increased since the emittance value of the green paint after three coats was lower (0.64) than the value of the white paint (0.78). The reduction in emittance observed with the green paint (with three coats) is likely due to less coverage of the aluminium surface, which caused part of the low-emittance natural substrate (0.06) to be more exposed.

Although characterization tests were not performed, the natural (unpainted) substrate was considered for comparison, and iron sandpaper visually presents greater roughness compared to the other evaluated substrates (aluminium, ceramic, and fibre cement). The iron sandpaper in its natural condition showed the highest emittance (0.93). Even though its composition includes aluminium oxide—a metallic material—it is important to note that during the anodization process, the material adheres with a resin that allows the grains to remain on the backing. This results in a high-emittance material in its final product condition. Additionally, due to the irregular shape created by the grains on the sandpaper surface, there is the effect of a large cavity with a small opening, which increases the energy absorption by the surface and consequently (for the same wavelength) the elevation of thermal emittance according to Kirchhoff's Law. However, it is important to note that the paint, in its liquid form, partially fills the cavities, reducing its depth and potentially altering the emittance. While these surface phenomena occur for all paints, only the silver paint caused a significant change in practice for the emittance of the sandpaper surface after painting, due to the presence of metallic pigments in its composition.

Spectral reflectance analyses of ceramic, fibre cement, aluminium and sandpaper samples reveal how the application of different paint colours and coats significantly influences the reflectance of the substrates. In unpainted ceramic samples (CerREF), the reflectance varies between 30% and 40% in the IR and VIS range, decreasing to approximately 10% in the UV. With the application of white paint, there was a significant increase in reflectance with each new coat, especially in the VIS range (~400 nm), where a peak was observed, followed by a sharp drop in UV. The silver paint produced a significant initial increase, but with less gain in subsequent coats, maintaining a relatively horizontal and uniform curve throughout the spectrum. The application of green paint resulted in IR reflectance values comparable to those of the unpainted substrate. However, in the VIS and UV regions, reflectance decreased significantly, with a progressive reduction observed with each additional layer.

In the case of fibre cement samples (FibREF), the reference curve showed stable reflectance values between 30% and 40% up to approximately 1900 nm, decreasing thereafter. The application of white paint on fibre cement also significantly increased reflectance, similar to that observed in ceramics, with a continuous increase in IR and a peak in VIS. The silver paint showed a more horizontal pattern, with a large increase after the second coat, but no significant change in the third. The green paint maintained reflectance close to the reference in IR, with low values in VIS and UV, reflecting a pattern similar to that observed in ceramics, with little variation after the first coat.

For the aluminium samples, which have high initial reflectance (>80%), the application of paint modified the curves differently. White paint initially reduced reflectance, but subsequent coats increased values, especially in VIS. Although it maintained the shape of the aluminium reference curve, the silver paint presented lower values than the unpainted substrate and minimal changes between coats. The green paint resulted in a general decrease in reflectance, with greater drops in the IR and UV ranges, maintaining a similar curve between coats, highlighting a peak around 500 nm.

Finally, in the sandpaper samples, which have very low reflectance without painting (<10%), the application of white and silver paints resulted in significant increases in reflectance, especially in the first coat. Even though there was an increase, the green paint had a smaller impact compared to the other paints. The values remained low, reflecting the initial characteristic of the sandpaper, but showing a pattern of incremental increase with each coat. The percentage variations in reflectance confirm that, while white and silver paints generally increase the reflectance of substrates, green paint tends to reduce or barely change the initial values, with specific differences depending on the type of substrate analysed.

IV. LIMITATIONS AND FUTURE WORKS

Among the limitations of this study, the use of reduced sampling is highlighted for each substrate and a limited variety of colours tested. Furthermore, an analysis of the chemical composition of the paints used was not performed. Only one paint application method was used (spray). Although there was repeatability in the measurements, a greater number could have been performed to increase the validation of the results and allow a more in-depth statistical analysis. Furthermore, a characterization of the roughness of the iron sandpaper could provide a more complete understanding of the effect of this parameter on the paint. Based on the limitations identified, some suggestions for future work include:

- Performing a comprehensive statistical analysis of the results to provide a greater understanding of the relationships between the increase in reflectance and emittance and the increase in the number of coats.
- Increasing the number of samples for each substrate.
- Exploring a wider range of paint colours to capture a more representative variety of the options on the paint market.
- Conducting a detailed analysis of the chemical composition of the paints used to better understand how different formulations can influence the results.
- Evaluating different paint application methods and comparing their impact on the final coating properties.
- Increasing the number of measurements performed to ensure a more accurate and comprehensive assessment of the characteristics of interest.
- Conducting a more in-depth study of the roughness of iron sandpaper and its effect on coating adhesion and durability, exploring a variety of sanding conditions and parameters.
- Evaluating the influence of paint layer thickness on solar reflectivity and thermal emittance.

V. CONCLUSION

This work presented the laboratory measurement of the thermal emittance and solar reflectance of four substrates after the application of each of three coats of paint in the colours white, silver, and green. The performed measurements of this property were based on the ASTM C1371 and ASTM E903 standards using a portable emissometer and a UV-VIS-NIR spectrophotometer, respectively. Although the number of substrates and paint layers used in this research was limited to three coats, the findings indicate that the final thermal emittance and solar reflectance value of a given paint varies depending on the combination of substrate type and the number of applied coats.

Regarding thermal emittance, the results obtained for the non-metallic substrates (ceramic, fibre cement, and sandpaper) for the colours white and green converged over the three coats of paint, with the maximum absolute variation observed in relation to the unpainted reference of each substrate being only 0.05. For the colour silver, the biggest influence of the number of coats on emittance noted, with the largest variation in relation to the reference being 0.65, was observed in the second coat applied to the fibre cement. The aluminium substrate showed a bigger influence on the measured emittance value. With each coat applied, there was an increase in its emittance regardless of the colour used. The greatest variation occurred for the white paint after three coats, with an increase of 0.72.

In relation to solar reflectance, the results demonstrate that both the number of applied coats and the substrate type significantly influence the measured reflectance. For example, for white paint on a ceramic substrate, the absolute reflectance increased from 0.429 with a single coat to 0.738 with three coats, representing a relative variation of 72%. Considering all analysed samples, the absolute variation reached a maximum of 0.35 from the first to the second coat and 0.19 from the second to the third coat. Further tests will be necessary to determine whether applying additional coats (four or five) would still have a significant effect on the final solar reflectance value, particularly for light-coloured paints applied to dark substrates.

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