BASIC DIGITAL IMAGE COLOR ANALYSIS FOR NON-DESTRUCTIVE TESTING OF SETTING AND CURING PROCESS OF BUILDING PRODUCTS:

Application to thin render layers sprayed at building site

Felipe Arturo Agena Kanashiro[1], Joan Lluís Zamora Mestre (corresponding author)[2]

Abstract

Many building products are put in place in liquid or plastic state. During first hours and days the product sets and dry changing their mechanical properties and their visual aspect also changes in parallel due to the hardening process. In the case of sprayed products, the technical supervisor must know at any time the quality of every sprayed layer and finally determine when it has reached its point of maturity that allows considering it as ready or suitable to receive the next layer. Experimented professionals often use personal visual ability to recognize the evolution of visual colors and surface textures of thin render layers applied on site as capacity to determine this right moment, especially in the case of dry mix sprayed products that harden progressively during curing process. However, these visual assessments are not considered decisive as a technical procedure to assess the evolution of the sprayed product properties.. As they are thin layers, it can be considered that the information acquired

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[1] Departament de Tecnologia de l'Arquitectura, Universitat Politècnica de Catalunya, ETS Arquitectura de Barcelona, Catalunya, 08021, Spain, ORCID 0000-0002-6818-9554, keiji_agena@hotmail.com

[2] Departament de Tecnologia de l'Arquitectura, Universitat Politècnica de Catalunya, ETS Arquitectura del Vallès, Barcelona, 08173, Spain, ORCID 0000-0002-7705-6171, (corresponding author), e-mail: joan.lluis.zamora@upc.edu

from their surface is sufficiently representative of their interior qualities. The aim of this study is to correlate information obtained in successive local measurements of humidity and penetration resistance taken on the early surface of a dry mix product just sprayed (Portland cement mortar and gypsum plaster), during its setting phase and compare with its surface digital color evolution during this process. The goal was to explore if it is possible to establish a relationship between evolution of resistance penetration and evolution of some digital image basic parameters during the setting and drying period. If this relationship were sufficient, conventional point-to-point contact tests (DT) could be replaced in the future by non-destructive (NDT) surface visual tests. This is very useful at building site where there are big surfaces to assess and short time to take right decisions.
Keywords: digital image analysis, non-destructive testing, setting process, curing process, sprayed building products

Introduction

Procedures to analyze the properties of materials without damaging them are known as non-destructive tests (NDT). These methods ensure that the properties of the material under analysis are not altered permanently by the test that is carried out. Nowadays, non-destructive tests for the construction industry tend to be less precise than destructive tests (DT), but on the contrary, they involve fewer occupational risks and minimal intervention in the building product to be evaluated, which means that its technical properties can be analyzed faster and at lower cost. All this allows that a much larger area can be inspected in each campaign and that the general knowledge acquired is greater. After the areas that pass the prior NDT general inspection and the areas that do not pass the NDT screening have been delineated, evaluations by destructive methods can be focused on the areas that are truly suspect. For a new non-destructive NDT method to be recognized as useful, it is essential, at the beginning of its study and development, that each of its measurements be carried out in parallel with another destructive measure already standardized and recognized to determine the validity and robustness of its area of application. The application of sprayed building materials is nowadays a fast and economical procedure because the availability of trained workers, affordable devices and products fitted to these technologies (Table 1). The building product is sprayed in successive layers of standard thickness of one or more centimeters. Between the applications of successive layers, it is advisable to wait from some hours to several days in order to ensure properly setting and drying. The decision on when to apply next layer is usually taken by contractors on-site to the best of their experiential knowledge and understanding. (Fig.1)

The aim of this study was to analyze during the setting phase the potential correlation between the evolution of drying and strength parameters, and changes in the histogram of its digital image. The initial hypothesis is based on determining the change in color that occurs on the surface of sprayed materials during the setting process, due to the material drying and gaining strength, and the possibility of correlating this change with variations in conventional parameters of consistency and humidity, measured with standardized equipment such as the penetrometer and hygrometer. If this were possible, an onsite quality control procedure would be available for the maturation process, based on the variation in color, a parameter that is easily measurable in real time, using portable hand-held equipment and even a smartphone.

State-of-the-art

APPLICATION OF SPRAYED BUILDING MATERIALS

The final quality of sprayed building materials depends on accurate setting and drying, phenomena strongly influenced by the environmental conditions in the surroundings and the previous state of the surface to be sprayed.

SPRAYABLE BUILDING PRODUCTS	APPLICATION
Cement mortar	Underground construction. Structural reinforcement. Retaining wall.
Gypsum plaster	Interior and exterior wall coating. Decorative finishes.
Polyurethane foam	Interior and exterior thermal and acoustic insulation. Facade waterproofing.
Perlite mineral wool	Structural fire protection. Thermal insulation.
Cork	Thermal insulation. Waterproofing. Facade restoration.
Mortar render	Facade coating. Floor covering. Roof coating.
Polymer coating	Waterproofing. Swimming-pools. Potable water storage.

Table 1: Main sprayable products and building applications.
Source: authors

Once the layer has been just sprayed, a period of time must be left before the spray rendering can receive other layers of finishing such as paint. Workers prefer to apply slow-setting sprayed pastes so that they have more time for manual corrections to recently sprayed rendering. This gives better control over the surface on which the work is being carried out as professional handbooks recommends [1,2,3,4].

To control the final quality of spray rendering, it is very important to carry out intermediate monitoring of the maturation process to ensure all is developing well, that is, the sprayed material is drying without cracking and gaining strength as professional associations good practices recommends [5,6]. Adherence to the support is a more complex aspect that we will analyze on future occasions. Therefore, two main variables must be controlled during the maturation process:

- penetration resistance, indicates the surface consistency that is acquired
- humidity of the sprayed paste, indicates the maturity that is acquired

Fig. 1: Methods of applying building products to a vertical surface using a sprayer. Left: mortar cement. Right: gypsum plaster Source: authors

IN-SITU EVALUATION OF THE PROCESS OF SETTING AND ACQUISITION OF STRENGTH OVER TIME

Due to the demands of execution, most sprayed materials require considerable paste consistency, a long time until the start of setting, and fast hardening. For this reason, many researchers are investigating additives that can provide these characteristics. Assessments of their success cannot always be carried out with non-destructive methods.

Adrien et al.[7] have proposed the use of interesting in-situ tests to observe in detail how the processes of formation of needle-shaped crystals evolve in the plaster during the setting process. Various tests have been carried out with different sizes of gypsum particles to determine their influence on hydration kinetics and on the final microstructure of the plaster. Other researchers[8] have monitored the change in grayscale of the surface of the Portland cement mortar through video image processing to assess in a non-destructive way the surface porosity of hardened cement mortar renders. Some research teams[8,9,10] have applied laboratory techniques to assess the reactivity of accelerants and the microstructure of hardened cement pastes produced by hand mixing or spraying.

Methodology

To preliminary verify the hypothesis a previous campaign was developed to assess the change in color that occurs on the surface of two sprayed products, cement mortar and gypsum plaster, due to the material drying and strength gaining, with a smartphone camera. Simultaneously conventional parameters of consistency and humidity were measured with standardized equipment such as the penetrometer and hygrometer. After the curing and hardening process all compiled data were contrasted searching any correlation. If this previous campaign succeed it will be possible in the next future to develop an onsite quality control portable procedure for assess the maturation process using portable hand-held equipment as smartphone and app specific software.

ASSESSMENT OF THE PENETRATION RESISTANCE OF SPRAYED MATERIAL

To assess this property, a test was carried out in accordance with the procedures established in ASTM Standards[11,12,13,14,15], and more specific ASTM C403/C403M-16, *Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance*. A portable static penetrometer was used that is specific for cement mortar, with values expressed in decanewtons (daN) and tips with circular cross-sections of different diameters (Fig. 2 left). For the measurement, the circular cross-section tip with the required diameter was selected. The red indicator was set at 0 N, and the penetrometer was pressed constantly until it penetrated the surface. The red indicator moved to the value in decanewtons (daN) that indicated how much force had been used, and then the daN were converted into newtons (daN x 10) and the result divided by the area in millimeters of the circular cross-section of the tip ($A= \pi \cdot r^2$) to determine the penetration resistance in megapascals (MPa).

$$PR\ (MPa) = R\ (daN) \times 10 / \pi \cdot r^2$$

As this is a preliminary study, the campaign has only been done on a single specimen for each sprayed product. The measurement area occupies only a lateral half of the specimen in order to have the simultaneous influence of the central and perimeter areas. The 16 rounds of 6 measures were realized successively in the same sector to be able to follow the evolution with continuity, always respecting the maximum and minimum separations established. The density of penetrations was therefore 1 for every 10 cm^2.

Penetrometer Hygrometer

Fig. 2 NDT portable devices used in this study
Source: authors

ASSESSMENT OF THE SURFACE HUMIDITY OF THE SPRAYED MATERIAL

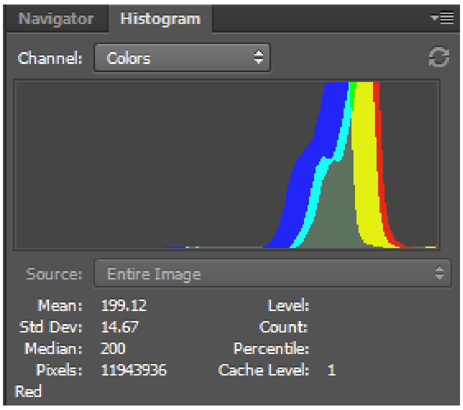
To assess this property, an "in situ" test was carried out with a portable hygrometer that measures the surface humidity of a material, such as the TESTO 616 hygrometer (Fig. 2 right) used in this study. This device is based on the capacity of water to alter electrical conductivity in a porous material. For the measurement, the type of material to be measured was selected using the button panel and the measuring plates were put in direct contact with the surface area. When the button was pressed, the percentage of humidity in the surface of the material appeared on the hygrometer screen, expressed as a percentage in weight of water compared to total weight. Although the measuring plates are only supported on the surface of the material, it is considered that the device measures humidity in materials at a depth of up to 5 cm. The measurements should be made in different places of the sample to accurate the results.

ASSESSMENT OF THE SURFACE COLOUR OF THE SPRAYED MATERIAL

Photographs were taken using the digital camera in a Motorola G4 Plus 16 Megapixels smartphone in an interior setting illuminated with a conventional white LED strip to achieve even lighting without distorting the color of the material. This strip was mounted below the camera support to avoid shadows on the material. The LED strip was placed parallel to the material rather than at a perpendicular angle to avoid overexposure of the photograph. In every round only one picture was taken and it was assessed without any previous digital processing. For all the photographs, the same light intensity and conditions were used. It was no necessary to use any digital or optical zoom.

The change in color of the sprayed materials during the setting and maturation process was analyzed, and at various successive moments the values of the color histogram were compared with the digital image that was obtained. For this research, we focus mainly in the color histogram, which is a representation of the number of pixels that each one of the colors contains and of how these are distributed in the digital image. To achieve this, the histogram function available in Adobe Photoshop CC 2015 software was used (Fig. 3) with any previous calibrating process at this research stage. The basic color histogram also offers the Luminosity values, parameter that represents the perceived brightness distribution of the image. The average between the RGB channels that make up the image brightness comes from different proportions: Green 59%, red 30%, and blue 11%, as green color is more important, since the human eye perceives this color more easily.

Histogram function



Color histogram analysis of a plaster sample image.

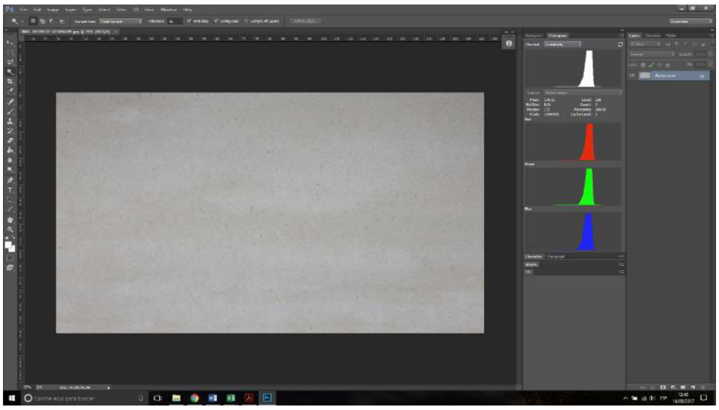


Fig. 3 Adobe Photoshop CC 2015. Computer screenshots.
Source: authors

Development

Samples, both gypsum plaster and cement mortar, were sprayed abroad over hollow fired clay bricks of 50 x 20 x 4 cm in order to facilitate their subsequent transport to the photography set. This set could not be assembled on site, due to the difficulty in controlling the light level and the safety protocol in place during the execution of spraying works.

To carry out the test for the plaster gypsum, a company specialized in the sprayed application of this product was asked for to visit a building site in order the authors can collect the samples for this study. The gypsum plaster was projected with a thickness of 1.5 cm. The product sprayed is commercial monolayer plaster gypsum Algiss Rubi[16] lightened with perlite, indicated for the rendering of interior facings. For gypsum plaster equipment the spraying equipment is a commercial PFP G4 standard[17].

Because the supporting brick is made of fired clay, an absorbent material, its surface was previously moistened with water. Since this support brick already had surface relief, it was not necessary to create an extra initial roughness. The manual regulation of the water flow in the projection machine allows the operator to control the homogeneity and consistency of the sprayed plaster. The day the plaster paste was sprayed (16/03/2017) the environmental temperature was around 14.5 °C and the relative humidity was 45% (Fig. 4 right) in the metropolitan area of Barcelona. The projection work area was adequately ventilated. The end of the gypsum paste setting was reached after past 4 hours, according to the product data sheet.

To carry out the test for the mortar cement, it was dosed and sprayed in a laboratory of the UPC, in the framework of the development of several doctoral theses[18]. The cement mortar was projected with a thickness of 7 cm. The mortar composition was of cement type I 52.R and calcareous aggregate. The limestone type was selected as it is the aggregate that provides the most suitable rheology for projection and for this reason is the most widely used in the building works. This aggregate has a specific mass of 2.32 g / cm^3 and water absorption of 5.46 %. Aggregate size varies between 0 and 1.25 mm and the fine content of the sand (passes 200 of 0.125 mm opening) is 9.13 %. The aggregate / cement ratio in sprayed mortars is usually 1.7. . The water / cement ratio is spray mortars is usually 0.506/1. A superplasticizer additive (0.01/1 dosage) based on a polycarboxylate solution (34% solute content) were used to ensure proper rheology of the mixture.

The base mortar mixing procedure was performed in a 65/2 K-3 type planetary mixer using 65 l containers. The rotation of the blades and the planetary speed were 150 and 40 rpm, respectively. Cement and water were mixed first for 4 minutes. The superplasticizer was added and the mixture was homogenized for an additional 4 minutes. Then the aggregate was added and mixed for another 5 minutes.

The base mortar mixture was kept at rest for 1 hour at controlled temperature (20 ° C) and humidity (90 %). After this period, the base mortar mixture was sprayed with the accelerator. This procedure sought to reproduce the real time that elapses during preparation at the concrete station, transportation to the site, and projection. Alkali-free accelerating additives and the rest of the water were finally added during the projection. On the day that the cement mortar was sprayed (22/06/2017), the environmental temperature was 28.5 °C and the relative humidity was 48 %. (Fig. 4 left)

The digital photographs (NDT) and the tests (DT) were carried are performed on the same samples and out in the following way:

1. The paste was sprayed onto the hollow brick of 50 x 20 x 4 cm in the same way that the material is applied on work site. Then, when the sample was received, it was immediately transferred from the site to the place nearby that has been prepared as photography set. The first photograph was considered to have been taken at minute 0, despite the time that had elapsed since spraying due to the short transport period (20 minutes) of the samples.

Spraying cement mortar at laboratory | Spraying gypsum plaster at work site

Fig. 4: Collecting sprayed samples for transport to the photography set.
(Source: authors)

Camera parameters s 1/20, ISO100. | Photographic set conditions

Fig. 5: Digital photographic conditions
(Source: authors)

2. The next photograph was taken after 30 minutes and, at the same time, measurements were made of humidity and penetration resistance (in the case of mortar, measurements of the humidity of the material could still not be taken, as the material was outside the humidity range permitted by the measuring equipment).

3. Successive photographs were taken every hour after minute 0, and the respective measurements were made (in the case of mortar, the material was still very wet some hours to be measured with the hygrometer).

4. The successive photographs were taken every hour after minute 0 and the respective measurements were made (DT: penetration test, NDT: hygrometer and RGB color.)(Fig. 5)

5. The same procedure was repeated, elonging interperiods of measurement, until the humidity arrives to 1-2 % values. At the end of this process, we had a photographic and statistical record of the humidity and penetration resistance necessary to analyze the material

Interpretation of the results

PLASTER GYPSUM

Once the results of measuring the penetration, humidity and digital color of the samples had been obtained, the data were organized into files with the parameters of each test and the respective line graphs showing the evolution of the properties during the setting process of the sprayed material. Table 2 sums up the values and figure 6 represents the associated graphs. The initial humidity (first 4 hours) was very high, and outside the maximum range that can be measured by the hygrometer (20 %). From a visual perspective, the surface of the material was initially uniform, with a slightly dark grey color and a slight shine. In addition, the presence of small bubbles and dips could be seen throughout the sample (Fig. 7 left). The sample changed luminosity from 167.57 to 187.64 in 72 hours after being sprayed. The value of luminosity, after an hour, rose to 171.36; this means that the sample became brighter than the initial tone. After 2 hours, the luminosity decreased again, and the same happened at 4 hours. At 6 hours, it began to increase, the sample became brighter and at 12 hours, the luminosity value (170.15) was higher than the initial value of 167.57. From this point, the luminosity value continued to rise until the end of the test, which means that the sample continued to get brighter until it reached the value of 189.45. At 72 hours, the luminosity stabilized and remained at 187.64.

It was not possible to measure penetration resistance in the first few minutes after the plaster had been sprayed, as the surface was too soft and the equipment that was used (penetrometer) could not register any values as its tip simply sank into the plaster with its own weight, without recording the force exercised daN. As product technical data sheet informs the penetration resistances increase fast the first 4 hours (work time) and from this increase slowly till reach 20,52 MPa after 72 hours after being sprayed.

The RGB levels initially indicated that the predominant color was red over green and blue, respectively. However, this difference got smaller. At the end of the test, the values were quite similar between the three color variables. The color values became brighter after spraying but the initial rising trend was interrupted between the first and fourth hours after the plaster spraying. However, after this time, the trend leveled out and the plaster continued to get brighter.

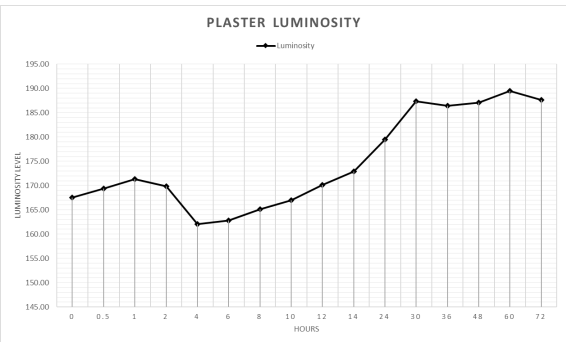
SPRAYABLE PLASTER GYPSUM TEST (1cm thickness)							
16/03/2017		DT	NDT				
Real Time	Test Time	Penetration Resistance (MPa)	Humidity	Luminosity	Red	Green	Blue
10:30	0 h	0	20.00%	167.57	169.03	167.37	163.76
11:00	0.5 h	0	20.00%	169.41	170.46	169.38	166.07
11:30	1 h	0.6	20.00%	171.36	172.03	171.33	169.36
12:30	2 h	5.31	19.60%	169.88	171.72	169.69	165.54
14:30	4 h	9.91	18.70%	162.07	163.92	161.92	157.63

16:30	6 h	11.68	17.40%	162.80	164.04	162.75	158.82
18:30	8 h	13.8	16.70%	165.08	166.53	164.8	162.22
20:30	10 h	15.57	15.60%	166.93	168.57	166.57	164.09
22:30	12 h	16.63	14.30%	170.15	171.57	169.85	167.53
00:30	14 h	16.99	13.50%	172.88	174.16	172.38	171.54
10:30	24 h	17.69	11.40%	179.49	180.48	179.11	178.13
16:30	30 h	18.4	9.30%	187.31	187.35	187.34	185.66
22:30	36 h	18.05	7.90%	186.41	186.97	186.36	184.81
10:30	48 h	18.05	4.30%	187.08	188.06	186.97	185.18
22:30	60 h	19.11	2.40%	189.45	190.4	189.39	187.24
10:30	72 h	20.52	1.40%	187.64	187.7	187.67	186.54

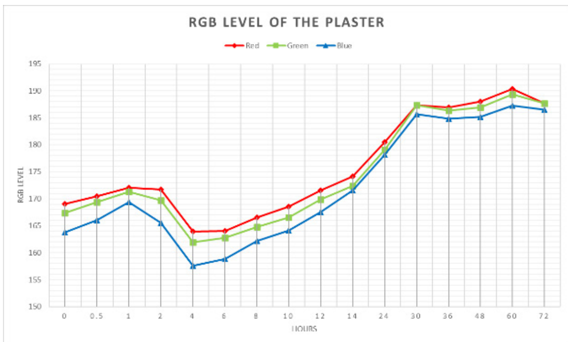
Table 2: Test results of plaster sample images. Second column shows the time elapsed since the start of the test. Source: authors

The test was ended on day 3, when the plaster gypsum no longer showed considerable changes and maintained a stable RGB and luminosity, the same as the resistance to penetration that remained at its maximum of 20.52 MPa, while the humidity was almost null (1.40 %) (Fig.7 right).

Luminosity levels of the plaster sample during the setting process



RGB levels of the plaster sample during the setting process.



Humidity levels of the plaster sample during the setting process

Penetration resistance levels of the plaster sample during the setting process.

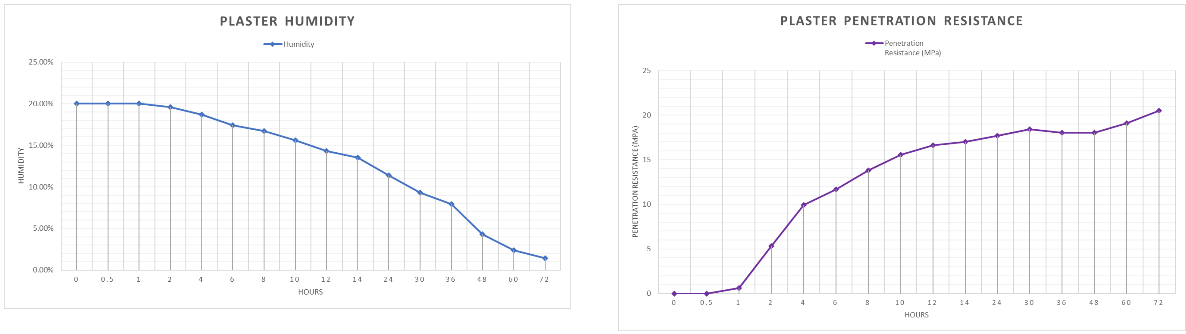


Fig. 6: Graphs of the different parameters measured in the plaster gypsum sample. In ordinate each parameter. In abscissa the values of time. (source: authors)

It therefore seems evident that three temporal stages can be distinguished: a first (1 hour) in which humidity decreases and the associated luminosity also increases, while resistance to penetration remains inactive; a second stage (2-24 hours) in which the drying process is not stopped, the process of increasing resistance to penetration clearly begins, but there is a bump in the progress of the brightness values; finally, in the third stage, full drying is achieved (24 - 72 hours), the hardening process slows down and also the process of increasing luminosity.

Real Time	Test Time	Penetration Resistance (MPa)	Humidity	Luminosity	Red	Green	Blue	Real Time	Test Time	Penetration Resistance (MPa)	Humidity	Luminosity	Red	Green	Blue
10:30	0 h	0	20.00%	167.57	169.03	167.37	163.76	10:30	72 h	20.52	1.40%	187.64	187.7	187.67	186.54

First image of the sprayed plaster sample.

Final image of the sprayed plaster sample

Fig. 7. Comparison between the appearance and values, initial and final, of the gypsum plaster sample.
(source: authors)

CEMENT MORTAR

Once the results of penetration, humidity and digital color measurements of the samples had been obtained, the data were organized in files with all the parameters of each test and the respective line graphs showing the evolution of the properties during the setting process of the sprayed material. Table 3 sums up the values and figure 8 represents the associated graphs. The initial humidity (first 4 hours) was very high, and outside the maximum range that can be measured by the hygrometer (20%).

In this case, rapid hardening of the cement mortar could be seen, probably due to the accelerator content in the mixture. Accelerators are commonly added to sprayed mortar, as it needs to harden fast but must be applied with a fairly liquid consistency so that the nozzle does not get blocked by the consistency of the mortar.

From a visual perspective, the surface of the sprayed mortar had an irregular appearance. It was dark grey and not at all shiny. As the surface of the material dried, small white spots appeared as time elapsed. The sample changed from dark grey (104.00) to light grey (132.08) in less than 6 hours after being sprayed (Fig. 9).

SPRAYABLE MORTAR CEMENT TEST (7 cm thickness)							
22/06/2017		DT	NDT				
Real time	Test time	Penetration Resistance (MPa)	Humidity	Luminosity	Red	Green	Blue
14:00	0 h	4.6	20.00%	104.00	108.89	104.23	90.71
14:30	0.5 h	6.72	20.00%	109.40	113.44	109.43	98.81
15:00	1 h	8.49	20.00%	108.32	112.7	108.05	98.66
16:00	2 h	10.26	20.00%	103.50	106.8	103.61	94.44
17:00	3 h	12.38	20.00%	111.77	113.62	112.03	105.25
18:00	4 h	14.15	18.90%	120.58	122.88	120.65	114.24
19:00	5 h	15.92	17.90%	128.51	131.27	128.5	121.55

20:00	6 h	18.75	17.10%	132.08	134.31	132.13	125.99
21:00	7 h	21.23	16.20%	135.95	138.44	135.8	130.27
22:00	8 h	24.41	15.10%	140.16	142.33	139.9	135.74
14:00	24 h	25	9.40%	161.56	163.7	161.57	155.85
14:00	48 h	25	6.50%	169.74	171.35	169.81	164.91
14:00	72 h	25	4.60%	170.24	171.72	170.17	166.53
14:00	96 h	25	3.50%	176.99	178.37	176.98	173.19
22:30	120 h	25	2.80%	176.24	177.59	176.28	172.21
14:00	144 h	25	2.40%	178.11	179.06	178.38	173.86
14:00	168 h	25	2.00%	183.15	184.41	183.19	179.29

Table 3: Test results of mortar simple images. Second column shows the time elapsed since the start of the test.
Source: authors

Penetration resistance increased constantly, while humidity dropped slowly during setting. A maximum penetration resistance of 25 MPa was reached. After this value, the sample could not be measured without being destroyed, so this was established as the maximum value. It is reached 24 hours after spraying.

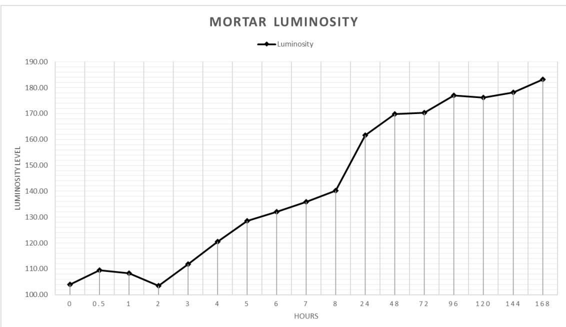
In terms of RGB values, the values of the three colors become more similar as time passed, but red always predominated, followed by green and blue, and this order was never altered. The color values became lighter after spraying. However, between the first and second hours, the sample got slightly darker before again becoming lighter in the third hour until the end of the test.

The test ended on day 7, when the mortar sample no longer showed considerable changes and maintained a stable RGB and luminosity, the same as the resistance to penetration that remained at its maximum of 25 MPa, while the humidity was almost null (2.00%).

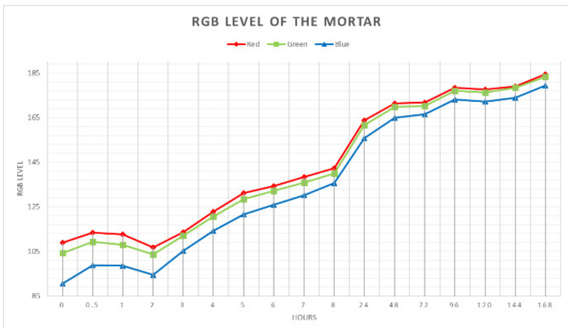
It seems clear then that three temporal stages can also be distinguished: a first (2 hours) in which the humidity remains stable and thus also the associated luminosity is maintained, while the resistance to penetration does not stop increasing; a second stage (2-8 hours) in which the drying process begins slowly, the process of increasing luminosity clearly begins and the resistance to penetration increases until it reaches its maximum value; finally, in the third stage (8 - 168 hours), drying is accelerated until reaching its maximum value, the hardening process remains stable and the process of increasing luminosity continues clearly.

If must be remarked that the cement mortar surface is rougher than the gypsum plaster surface and because of this is not homogeneously illuminated. Soft shaded areas may occur and alter the results of this preliminary assessment. However it seems that this different roughness coating does not seem to have affected the first results. The study of this variable must be scheduled in future campaigns.

Luminosity levels of the mortar sample during the setting process



RGB levels of the mortar sample during the setting process.



Humidity levels of the mortar sample during the setting process.

Penetration resistance levels of the mortar sample during the setting process.

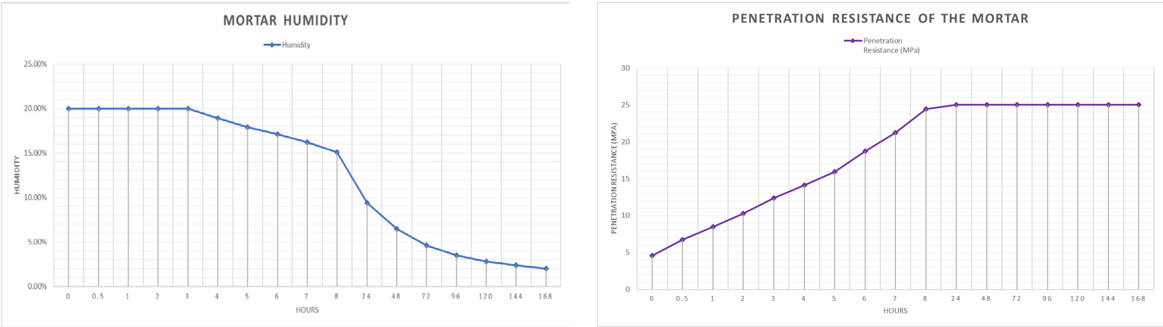


Fig. 8: Graphs of the different parameters measured in the cement mortar sample. In ordinate each parameter. In abscissa the values of time. (source: authors)

eal time	Test time	Penetration Resistance (MPa)	Humidity	Luminosity	Red	Green	Blue	Real time	Test time	Penetration Resistance (MPa)	Humidity	Luminosity	Red	Green	Blue
14:00	0 h	4.6	20.00%	104.00	108.89	104.23	90.71	14:00	168 h	25	2.00%	183.15	184.41	183.19	179.29

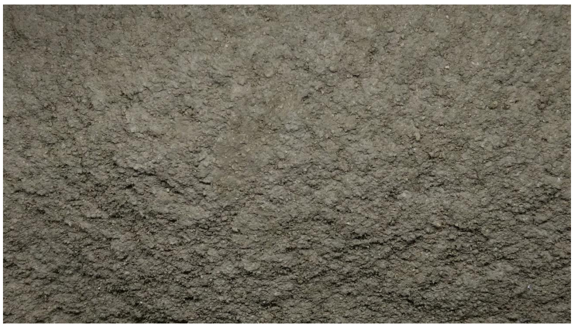


Fig. 9: Comparison between the appearance and values, initial and final, of the cement mortar sample. (source: authors)

Results and Discussion

The result of the tests showed regularity in the evolution of the assessed properties of the sprayed materials analyzed during the setting process humidity, penetration resistance, color and luminosity. However, further future developments should be oriented to the study of this intermediate stage of the setting period when the color and luminosity values decline for a few hours coinciding with the work period in which the manufacturers of these products advise to manually manipulate the coating to adjust the finish surface. The future focus must be oriented to the study of differential changes between the surface and the interior of a material layer during the setting and drying phase and the role of additives that speed up or slow down certain chemical processes to improve the comfort of the applicator operators, which will slow down or speed up certain properties.

It is important to add that the detailed study of the RGB channels does not seem to have provided more information than the brightness itself. At no time has the balance between channels been altered and its evolution has always been parallel to that of luminosity.

This study contribute to the immediate interest of the technical community by linking 'visual' properties with technical ones and opens the door to considering the potential future viability of undertaking non-destructive tests to control the quality of relevant properties in sprayed materials through the use of color processing of digital images from the material's surface. Mobile applications are already available such as the Free Histogram Generator, which can analyze a digital image and indicate the levels of luminosity and RGB through a histogram, which is similar to that used in this research with the Photoshop CC 2015 software. In the near future, this type of application could be programmed so that the value of luminosity and color of a digital image could be associated with the values of penetration resistance and humidity of sprayed materials.

Therefore, preliminary onsite information can be obtained that is useful for taking faster decisions to organize the process of implementation. In no case this procedure can replace current specialized processes of evaluation that are more expensive, slower and complex but also more rigorous and reliable, which is why they are included in current standards.

However, a lot more tests need to be carried out to develop this NDT procedure and ensure that it is the enough accurate and reliable possible. For future research, the following aspects should be considered:

- relevance of the meteorological conditions during projection, setting and drying process.

- modification of the drying and hardening conditions, depending on the function of water absorption of the support.

- comparison of images taken at different areas of the same rendering to assess the gradients of speed of drying and speed of hardening.

- sensibility to different projection devices, digital cameras optical parameters or image processing software.

- evolution of bighting in the first hours.

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References

1. Asociación Técnica y Empresarial del Yeso, *Ejecución de Revestimientos con Yeso*. (Ed. Universidad Politécnica de Madrid, 2016). Retrieved from: http://web.archive.org/save/https://www.sulaplanet.com/images/pdf/MANUAL-ATEDY-YESOS.pdf

2. L. de Villanueva Dominguez, A. García Santos, *Manual del Yeso (*CIE Inversiones Editoriales Dossat, Madrid 2001) ISBN: 9788495312464

3. M. Fernández Pérez, J. Costal Blanco, J.I. del Campo Domínguez , 2004. *Guarnecidos y enlucidos con yeso*. *Guía práctica para el profesional albañil,* (Ideas Propias, Vigo, 2004). ISBN: 9788498390025

4. Sika, *Hormigón Proyectado, Sistemas de Aplicación de Productos Sika en el Hormigón Proyectado*. Retrieved from: http://web.archive.org/web/20200820164209/https://esp.sika.com/dms/getdocument.get/03fffe32-4b95-31cb-948e-dd65fc15b0bf/L74STATEMENTHORMIGONPROYECTADO.pdf

5. H. Kdapperich, R. Pöttler, and J., Willocq, *Shotcrete for Underground Support VII*, (American Society of Civil Engineers, 1995). ISBN: 0784400873, 9780784400876.

6. American Concrete Institute and Sprayed Concrete Association. ”The Proceedings of the ACI/SCA International Conference on Sprayed Concrete/Shotcrete: Sprayed Concrete Technology for the 21st Century*”*. (Edinburgh. S.A., Austin. ISBN: 0419222707, 1996).

7. J. Adrien, S. Meille, S. Tadier, E. Maire and L. Sasaki, “In-situ X-ray tomographic monitoring of gypsum plaster setting”, *Cement and Concrete Research,* vol 82, april 2016, pages 107-116, ISSN: 00088846, https://web.archive.org/web/20210122091930/https://www.sciencedirect.com/science/article/abs/pii/S0008884615003051?via%3Dihub

8. Z. Liu, X. An, S. Li., “A non destructive method for evaluating the impermeability of mortar based on image processing”, *Construction and Building Materials,* Volume 131, 30 January 2017, Pages 467-475 ISSN: 0950-0618, https://web.archive.org/web/20210122092105/https://www.sciencedirect.com/science/article/abs/pii/S0950061816318062?via%3Dihub

9. S.P. Renan, S.H.P. Cavalaro, M. Concotto, and A.D. de Figueiredo , "Influence of spraying on the early hydration of accelerated cement pastes", *Cement and Concrete Research,* vol. 88 October 2016 pages 07-19, ISSN: 0008-8846,
https://web.archive.org/web/20210122092243/https://www.sciencedirect.com/science/article/abs/pii/S000888461630179X?via%3Dihub

10. S. Renan P., S.H.P. Cavalaro, M.A. Concotto, and A.D. de Figueiredo, "Parameters Controlling Early Age Hydration of Cement Pastes Containing Accelerators for Sprayed Concrete", *Cement and Concrete Research,* vol. 89 November 2016 pages 230-248, ISSN: 0008-8846,
https://web.archive.org/web/20210122092425/https://www.sciencedirect.com/science/article/abs/pii/S0008884616305026?via%3Dihub

11. *Standard Test Methods for Physical Testing of Gypsum, Gypsum Plasters and Gypsum Concrete,* ASTM C472-20 (West Conshohocken, PA: ASTM International, approved May 3, 2020).

12. *Standard Guide for Preliminary Evaluation of Comparative Moisture Condition of Concrete, Gypsum Cement and Other Floor Slabs and Screeds Using a Non-Destructive Electronic Moisture Meter* , ASTM F2659-10 (2015) (West Conshohocken, PA: ASTM International, approved F06.40 May 1, 2015).

13. *Standard Test Method for Calibration of Hand-Held Moisture Meters on Gypsum Panels,* ASTM C1789-14 (West Conshohocken, PA: ASTM International approved C11.01 May 1, 2017).

14. *Standard Test Method for Time of Setting of Hydraulic Cement Mortar by Modified Vicat Needle*, ASTM C807-18 (West Conshohocken, PA: ASTM International approved C01.30 October 11, 2018).

15. *Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance,* ASTM C403 / C403M - 16 (West Conshohocken, PA: ASTM International C09.23 revised 2016).

16. Algiss Rubí Single-layer mechanical spraying gypsum plaster lightened with perlite, https://web.archive.org/web/20210122095501/https://corporate.pladur.com/en/category-products/yesos-y-masillas-algiss/yeso-algiss-rubi-v-pi53599/

17. PFP G4 standard continuously and full automatically mix and pump all ready-mixed dry mortars suitable for machine use and on gypsum, lime and cement base with water into ready-to-use mortars, https://web.archive.org/save/https://www.pft.eu/www/en/produkte/produktprogramm/mischpumpen/mischpumpe.php?stein_id=876&system_id=172&lv_id=5

18. C.M. Herrera Mesén, "Evaluación de mezclas proyectadas: comportamiento y durabilidad",(master's thesis, Universitat Politècnica de Catalunya,2017). Retrieved from https://web.archive.org/web/20210122093024/https://upcommons.upc.edu/handle/2117/116001?locale-attribute=en