An investigation on the efficiency of water-jet technology for graffiti cleaning

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Abstract: The scope of this study is to investigate the possible usage of water-jet technology for graffiti cleaning and to find the best operational conditions. First, 11 different operational conditions of water-jet were applied into the pre-painted marble surfaces, then, image analysis methods were used in order to evaluate the conditions and find out the best one. After that, roughness features of the marble samples were measured, because water-jet application can cause excavation which may affect on the stone surface. Finally, it is concluded that water-jet machine can be used for graffiti cleaning with specific operational conditions which are selected by using both image analysis and roughness test results. Economic considerations of water-jet application are also carried out.

Response to Reviewers: Dear Editor Patrizia Tomasin, dear Reviewers, thank you for your letter and the Reviewers' comments concerning our manuscript entitled "An investigation on the efficiency of water-jet technology for graffiti cleaning" (Ref. No.: CULHER-D-15-00271R1).

All the reviewer's suggestions were appreciated and accepted. The changes in the manuscript, legend and tables' captions are written in red.

Dear Editor,

thank you for having copied all the reviewer's annotations, everything was clear.

We have now corrected our manuscript, following the suggestion of the reviewer, in order to make it acceptable to be published in *Journal of Cultural Heritage* (ref. no, CULHER-D-15-00271R1).

Changes in the manuscript are written in red.

Reviewers' suggestions were very useful to our work.

Cordially yours,
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Answers to Reviewers

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*Manuscript

An investigation on the efficiency of water-jet technology for graffiti cleaning

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Abstract

The scope of this study is to investigate the possible usage of water-jet technology for graffiti cleaning and to find out the best operational conditions of water-jet machine as cleaner. For this goal, Carrara marble was selected as a test stone. Three samples were prepared and 12 different areas were determined on them. Then, different operational conditions of water-jet were applied into these twelve pre-painted marble surfaces. These different operational conditions involve different travel speed, water pressure or inter-distance between passes of the machine to figure out the best combination. After that, image analysis methods were used in order to evaluate the conditions and find out the best one. In addition, roughness features of the marble samples were measured, because water-jet application can cause excavation, which may affect on the stone surface. Finally, it is concluded that water-jet machine can be used for graffiti cleaning with specific operational conditions, which are selected by using both image analysis and roughness test results. As a conclusion it can be said that; if the stone is painted heavily, then travel speed of the machine must be reduced. Oppositely, if the stone is slightly painted the best solution is to increase both the inter-distance between passes and the travel speed of the jet. Economic considerations of water-jet application are also carried out.

Keywords: graffiti cleaning, marble, water-jet, image processing, roughness measurement

1. Introduction

Graffiti is a form of damage -of relatively recent origin- that spoils the facades of buildings, shop windows, advertising panels, public transport, telephone booths, monuments, etc., involving writings, paintings, drawings, etc. usually with spray paints and, more rarely, even with special felt pens [1]. The phenomenon is typical of almost all cities (large and small) in industrialized countries and involves everywhere, several thousand square meters, while the average height of damaged areas generally does not exceed three meters (for evident reasons of "reach"). Relative economic damage is extremely high and is currently estimated, on a world scale, at much more than one billion dollars/year [1]; moreover, when graffiti appears on a world heritage site, the effect can be catastrophic. The agents in spray paints (the most widely used) normally contain a variety of pigments that determine the colour of the paint, binders (acrylics, glycerolphthalics, cellulosiacs, etc.), various additives (such as plastifying agents to improve adherence) and solvents (ketons, esters, hydrocarbons, etc.), as well as all kinds of propellant (freon, propane, butane and their blends, etc.) used to expel the liquid and form the jet of spray paint [2].

Sanmartín et al. [3] gave a review of methods of graffiti removal currently used. Effective defence against damage caused by graffiti in practice involves two different techniques:

a) Cleaning the spoilt surface, normally using specific solvents or even by means of sand-blasting;

b) Preliminary protection of surfaces at risk by applying suitable products forming protective barriers (protective paints, waxes, polymers) preventing contact between the base material and the graffiti.

More modern techniques, based on laser, have demonstrated the advantage of the fibre optic deliveries in the removal of graffiti on monuments [4, 5, 6]. Novel approach to graffiti removal based on bioremediation is still on experimental stage [7].

It should be stressed that any anti-graffiti to be used for the protection of stone monuments, buildings and street furnishings has to be evaluated for its acceptance or rejection by considering stone properties (porosity especially), paint characteristics and properties of anti-graffiti as colour and gloss, waterproofing and durability properties and cleaning efficiency [8].

The method proposed in this study to remove graffiti, is based on plain high-pressure water-jet. This cleaning method has a slight low damage potential on stone materials when its operating parameters are combined in an optimized way [9]; however, this technique is to be applied on not-polished stone because a slight excavation carried out by the water-jet. Differently from a recent study [10], the method proposed in this study uses neither abrasive particles nor chemical addictives in cleaning action. Therefore, any chemical effect does not occur after its application.

In order to assess the results of the proposed cleaning test, strategic tools as image processing and roughness measurements were used to compare natural, painted and cleaned surfaces in detail. Image analysis or image processing (IP) is basically the realisation of almost all performances of human visual system by computers, including colour or tone detection, object and edge detection, image segmentation and rendering, image classification and identification [11]. IP has become very popular method, which has been widely used in different research areas in last decade. One of these areas is earth science or much specifically mining industry for different reasons, such as: determining size distribution of aggregates [12], froth size control in flotation [13], controlling crushing and grinding circuits [14], determining some features of rock masses [15], identification of minerals [16], estimation of metal content [17], controlling the environmental effects of mines [18] or predicting of particle size distribution in bench blasting [19]. There are also several image processing related studies in the natural stone industry for colour identification of marble products [20], classification of final products or the texture recognition of pre-products of natural stones [21]. In addition, IP and IP-related methods are used: for monitoring the state of conservation of cultural heritage objects surfaces [22], for detecting, tracking and measuring the structural problems of monumental buildings [23], for digital preservation of cultural heritage by using 3D reconstruction methods [24-25], for monitoring the surface soiling and external effects on the historical heritage in Oxford, England [26]. Spectral imaging methodology is used to monitor on-line, non-destructively and in situ the cleaning level of pollution encrustation on stonework [27]. IP is used for virtual restoration of artworks [28]. Image analysis methods and flatbed scanners are used to identify, map and quantify the macro-porosity of mortar samples taken from the Roman hemicycle theatre in Sibari (South Italy) [29].

It's should be stressed that, for a correct assessment of the cleaning method proposed here, image processing has to be completed with the data coming from roughness measurement, as explained hereafter. Moreover, it's strategic to highlight that the study presented here is a part of a research project that includes also cleaning test using abrasive water-jet on different types of stone.

2. Materials

At the beginning of the study, Carrara marble samples were used for the tests to apply suggested method. More precisely the commercial name of the marble is Veined Marble C [30] and it's quarried near Carrara (Italy). This material was selected as a test stone in order to choose a marble type which has been commonly used in the European historical heritage as building stone or situates so that it would be commonly involves the 'graffiti pollution issue' in modern era: Carrara marble seems to be the best for this aim.

All the samples were sized 30 cm length, 10 cm width and 2 cm thickness. Some of the physical and mechanical properties and grain size features of the natural stone are given in Table 1. The physical and technical properties were determined by laboratory tests, which were carried out in accordance with ISRM [31].

In addition to physical and mechanical properties, the thin sections of this natural stone were also prepared and then were examined under a polarized microscope to determine the textural features and the petrographic description. The stone shows a granular 'saccharoid' texture, fine and compact; the structure is homeoblastic/granoblastic with exclusive presence of calcite granoblasts in a polygonal shape or, subordinately, non-oriented allotrimorphs in small sizes (0.2 - 0.6 mm). Microphotographs of Veined Marble C are shown in Figure 1 in both parallel Nicols (a) and crossed Nicols (b).

Table 1. Physical and technical properties of Veined Marble C.

Figure 1. Microphotographs of Veined Marble C in Parallel Nicols (a) and Crossed Nicols (b).

3. Methods

The study involves evaluation of the operating parameters of water-jet machine and the assessment of their optimum combination. For this goal, first, marble samples were obtained and painted by spray paint just as graffiti painters do. Then, 11 different operation conditions of water-jet machine were determined and applied as a cleaner tool onto eleven different painted parts plus one non-painted part by using these different operation parameters. After this step, we have 12 different cleaned-painted parts on the marble samples. Then, image-processing method was used in order to investigate and evaluate the operation conditions of water-jet system by evaluating these painted-cleaned samples. In addition to image processing, roughness features of the stones were also measured. The results were then compared with those of the unpainted surface. The methodology followed in this study is schematically presented in Figure 2.

Figure 2. The methodology followed in this study

3.1 The Equipments

Three main device/instruments were used in this study: a high-pressure water-jet system, an image processing system and roughness comparator for surface roughness tests.

The high-pressure water-jet system including a water-jet cutting robot called 'Waterline1620', provided by Tecnocut (Italy), was used for the experimental cleaning tests of the stones. All these cleaning tests were performed at the DICAAR (University of Cagliari, Italy). The system was modified by adding a device for adjusting water-jet inclination angle, which is necessary for different cleaning alternative applications. The water-jet machine is provided with a 50 kW intensifier pump, which supplies a maximum water pressure of 390 MPa at a flow rate of 7 L/min. The numerical control robot is supported by a steel load bearing structure on the work surface (1.6 m×2.0 m). This moves automatically along two axes (X and Y) with a maximum traverse speed of 40 m/min. The Z-axis is moved manually. Underneath the work bench is a water-filled tank that serves the dual purpose of collecting the debris and dampen the water-jet power. The cutting head is fitted with a sapphire nozzle and a 12 cm long focus tube with internal diameter of 1 mm. The control module, which governs the whole system, is interfaced to the machine via an automatic programming system CAD-CAM (WCAM2k).

In order to carry out the image processing tests, an IP software developed by one of the authors, was used. To apply image analysis methods for 2D images, the software was modified and re-compiled for this specific study. It can open different types of image files, scan their pixels and read colour values. After scanning/reading process, the program can save all colour data associated with their location in an individual text file. Several statistical values such as max, min, mean and standard deviation for colour values of any image are calculated during the process; these results are then saved in text files. In addition, for any image file, colour value distribution, histogram and distribution characteristics such as kurtosis or skewness values are also calculated by the software. If any user wants to apply extra statistical or mathematical application, she/he can easily use raw image data saved in text files. On the other hand, colour value of any pixel or a group of them can be changed, input image files can be converted into grayscale or another colour form; colour space conversations can also be applied with the program.

The crucial part of any image processing application is to obtain images under the same conditions for avoiding unwanted external effects such as light, shadow or pixel size or camera capacity, because these parameters directly affect the colour and brightness values of pixels and this may cause important problems during the analysis and processing. For this reason, closed small places –like cell- with controlled lights are commonly used for image processing applications. Another way to work under the same condition is to use a scanner if available. Therefore, in this study, a scanner was used to scan the stone samples under the same conditions with high pixel resolution.

Image processing alone is not sufficient to assess the success of stone cleaning, because it does not give any information about surface features of stones. It is necessary to keep in mind that the surface roughness of the stone, after cleaning, must be as similar as possible to that which it had before the painting. For this reason, it's strategic to carry out roughness measurement before the painting and after the cleaning.

Based on previous studies about stone finishing by water-jet [32, 33], roughness profile were carefully analyzed by using a mechanical comparator (rugosimeter). To measure the roughness features of the cleaned stone surfaces, the S3P rugosimeter (provided by Feinprüf Perthen GmbH) was used.

3.2 Plain Water-jet Test

During the study, 11 different operation conditions of water-jet machine were set in order to use it as a cleaner tool onto 11 different painted parts plus one non-painted part of stone surfaces. The different operational condition features of the water-jet machine are given in Table 2. In this table, the data in the last column describe the condition of the sample after the painting and before the cleaning. A view from the study of graffiti removal action by water-jet is given in Figure 3.

Based on the results obtained from earlier investigations [34, 35], nozzle diameter ϕ (0.3 mm), water-jet inclination γ (30° with respect to the horizontal plane), stand-off distance D (100 mm) and machining program for parallel rectilinear passes were kept constant; the operating parameters as the inter-distance between passes *I*, travel speed v_t and water pressure *P*, considered in the experimental plan, were varied as listed in Table 2.

Table 2. The different operational condition features of the water-jet machine.

Figure 3. A view from the cleaning process by water-jet machine in the test laboratory.

3.3 Image Processing Application

After the cleaning applications with water-jet under 11 different operational conditions, we have painted and cleaned marble stones with different painted/cleaned areas; 3 of these 11 areas are on the first sample (Figure 4).

Figure 4. The first marble sample with painted and cleaned areas.

The main consideration of the image processing in this study can be explained as follows. In order to scan the stone surfaces properly for having suitable image data, which is used as input data for image processing, twin square areas were determined with specific condition for scanning; one of twin squares is on the painted part, the other one is on the cleaned part so that the colour differences in between these areas help to measure the degree of the cleaning process for that specific area. Every twin square on the samples contains about 250.000 pixels (500x500) (Figure 5).

Figure 5. The twin square on the surface are considered to scan and compare.

With this consideration, square-shaped five twin squares were determined on one water-jet application area for scanning. Sixty different twin squares, for 12 different water-jet application areas, were determined in total on the marble samples. These couples were named as A1-P-01, A1-C-01 and so on. ‘A’ refers to the water-jet application area (A1-A12), ‘P’ indicates “painted area” and ‘C’ indicates “cleaned area”.

We have one diamond-saw blade surface area which is neither painted nor cleaned (A1-P), one water-jet cleaned after the diamond-saw blade surface area (A1-C) and 11 painted (A2-P…A12-P) and cleaned (A2-C…A12-C) areas as couples in order to test and analysis. The scanning areas on the one of three stone samples are shown in Figure 6.

Figure 6. The sample areas on the marble surface (sample P06).

At the beginning of the scanning process, input image files were colourful which means three different colour values among 0-255 per pixel and this makes more than 16 million different colour values per pixel which is too much for any kind of statistical method/calculation. Thus, it is needed to transform the colourful images into grayscale images. This is very common pre-treatment for almost all image-processing applications. Although, there is no one unique formula for this conversion, the one we used here (1) is the most common one and it forms a weighted average to account for human perception [36]. After this conversion, every pixel has one single colour value from 0 (black) to 255 (white).

$$Grayscale = 0.299*R + 0.587*G + 0.114*B \quad (1)$$

The marble we used for the tests is a crystallized marble which has light colour like white with soft dark veins, it is the same as so many monuments or statues in big cities, and the colour we used for graffiti during the tests is red which is also very common for graffiti. In grayscale after the conversion, light colour codes (higher colour vales up to 255 = white) indicate the marble surface; darker colour codes (small colour values down to 0 = black) refer to red coloured parts, which is graffiti paints. After this conversion operation, the image analysis method used here has three essential ideas:

I) The cleaning process is, in fact, kind *of turning colour from red (the colour of painting) to white* (natural colour of the stone) or with other words *turning smaller colour values into higher ones*.

II) When the cleaning process is approved as *smaller colour values into higher ones*, then, the colour differences in between painted and cleaned surfaces show the achievement of the cleaning process. The highest difference indicates the best cleaning achievement.

III) There is a specific area, which was not painted on purpose (A1). This part of the stone has diamond-saw blade surface because the marble samples were cut by diamond-saw blade. The point is that this part was also cleaned by water-jet (A1-C). There is no painted point in this specific area so that the colour features of this area show the features of the water-jet cleaning application without red colours (See Fig. 5). Which means that this area is kind of "target" area of the cleaning process, because by cleaning, we want to achieve a cleaned surface without red points.

After the scanning process, the colour values and statistical results for painted (Table 3) and cleaned (Table 4) areas are obtained.

Table 3. The Colour and Statistical Values of the Painted Areas

*Diamond saw blade surface (not painted)

Table 4. The Colour and Statistical Values of the Cleaned Areas

**Water-jet cleaned surface (not painted)

The differences in between painted and cleaned parts are calculated (i.e. for A1; A1P-A1C = 240-237 = 3 is found). All differences are given in Table 5.

Table 5. Change in colour with cleaning (P-C)

To investigate the excavation effect of the water-jet on the stone, the water-jet was used on a small part of the stone samples where there was no painting. In this local area, there are again five square couples; one represents the natural surface (diamond-saw blade surface) of the stone and another represents the excavated stone surface with water-jet. One of those five couples is given in Figure 7 and the data measured from these areas are given in Table 6.

Figure 7. The square couple on non-painted surface for comparing

Table 6. The Colour Values of Non-Painted Area

The data come from this specific area give very important information including the colour features of the stone itself and more important, excavation effect of water-jet application. Moreover, this natural surface and its data can be used as 'control data' for benchmarking. Degree of difference from the natural surface gives the information about the degree of cleaning. The colour differences in between cleaned surfaces and diamond-saw blade –raw-marble surfaces are given in Table 7. The difference from the water-jet cleaned surface without painting is given in Table 8.

Table 7. The difference from the diamond-saw blade surface

Table 8. The difference from the water-jet cleaned surface

In addition to the statistical analysis of the colour values, we have another image analysis technique to compare different images: comparing colour histograms visually. The colour histograms are the best tools to show similarities and differences quickly and easily. It gives a direct visual estimation. In the first part of the histogram analysis, the differences in between painted and cleaned areas were compared by comparing their colour histograms. The differences/similarities of the painted and coloured histograms indicate the success degree of the cleaning process. One good example (A5) with high differences and one bad example (A10) with similarity are given in Fig. 8(a) and Fig. 8(b) respectively.

Figure 8a. The colour histograms of A5-P and A5-C

Figure 8b. The colour histograms of A10-P and A10-C

In the second part of the histogram analysis, the colour histogram of the water-jet cleaned area was selected as the target area and we tried to find the best fitted histogram and its area. Again, one good example (A5) for the best fitted and one bad example (A2) for discordant histogram are given in Fig8(c).

Figure 8c. The histograms of the target area and good and bad examples.

3.4 Roughness Test

Although image analysis gives very important information about the colour of stone surfaces, it doesn't say anything about the roughness of surfaces. In fact, a cleaned surface, which shows similar colours compared to unpainted surface may have completely different roughness features due to an excessive excavation caused by the water-jet during the cleaning process. For this reason, the roughness profile of the cleaned samples was carefully analyzed using a mechanical comparator (rugosimeter). In particular, parameters R_a (mean roughness), R_{max} (maximum roughness depth) and W_t (waviness depth) were determined in accordance with DIN 4768 [37] and UNI EN ISO 4287 [38].

4. Results

After the cleaning process and just before the image analysis tests, the stone samples were controlled by naked eye for macroscopic control; according to this observation, followings can be said: in the first sample (P06), there are no differences between cleaned surface and saw-blade surface in the area A1. A2 and A3 parts looks have the same cleaning level, although A2 looks a little bit better. On the other hand, the second sample (P07) looks cleaned better; especially the area A5 looks very white like the natural stone colour. Finally, the last sample (P08) looks like it has cleaned areas and they have nearly the same cleaning levels such as A10, A11 and A12 look like having the same cleaning levels; A09 has a little bit better white areas comparing to others. These are the macroscopic observations, in order to see the detailed results we need to apply image analysis and roughness tests.

4.1 Image Analysis

The following results have been observed from the image analysis application:

1. Mean colour values of the painted areas. A1 has the highest colour value (the lightest colour), but it was not already painted. In this case, A6 has the lightest colour, which refers light red colour in this study; A11, A12 and A10 follow it. The smallest colour value (the darkest red colour) is measured on the A5; A9, A4 and A8 follow it, which mean that the darkest red colour is on these areas (Table 3).

2. Cleaned areas. A1, which was not painted, has the highest colour value (the lightest colour). Then, A4 has the lightest colours; A10, A8, A6 and A5 follow it. Higher colour values refer to white or more like white colours. On the other hand, the smallest colour value (the darkest colour) was measured on A2; A9 and A7 follow it.

3. The mean of standard deviation is 12.6 for painted areas, and 10.2 for cleaned areas. The average coefficient variation value is 19.8 for painted areas, but only 5.1 for cleaned areas. Skewness is a measure of lack of symmetry of distribution of data. Skewness value of normal distribution is zero, which means that normal distribution has perfect symmetry. Kurtosis also gives an idea about distribution characteristics of colour values. It shows the peak or flat form of the histogram. According to measured data, the skewness and kurtosis values of the painted samples were not dramatically changed with water-jet cleaning process (Table 4 and Table 5).

4. Table 5 is very important and shows the colour changes made by cleaning process between painted cleaned areas, according to these results, the highest change was measured on A5; A4, A8, A3 and A9 follow it. These results show that the cleaning process caused high colour changes in these areas respectively higher than other areas.

5. Table 6 shows that the water-jet application does not change the colour properties of the non-painted stone surface (the colour value is 240 for diamond saw blade surface and is 237 for water-jet cleaned surface). The other statistical values are also nearly the same. This is very important result, which indicates that the water-jet machine does not affect the colour feature of the applied surface and the only change in colour of the stone comes from the cleaning process, so that we can measure its success by using colour/image analysis.

6. Comparing to diamond-saw blade surface (Table 7). The most similar area to diamond saw-blade surface is A4 and A8, A6, A10 and A5 follow it. The most dissimilar areas are A2 and A9.

7. Comparing to the non painted but cleaned surface (Table 8). The most similar areas to the non-painted but cleaned surface are A4 and A6; A8, A5 and A10 follow it. The most dissimilar areas are A2 and A9. According to other statistical parameters, there are some changes only on A2, A3 and A9; other areas have nearly the same value.

8. According to the histogram analysis, A5, A4, A8 and A9 have good cleaning results. Our program has prepared more than 25 colour histograms for the analysis; the characteristic ones can be seen in Figure 6.

4.2 Roughness Test Results

The measured values (expressed in micrometers) of R_a, R_{max} and W_t were processed and then compared with those obtained for the original unpainted saw plane sample (Figure 9).

Figure 9. The results of roughness analysis carried out on the painted/cleaned samples.

According to the roughness test results, at first glance, A7 seems to be the best solution when the similarity is considered to the original part (sawplane surface), but this is not true. In fact, image analysis shows that A7 is not good option and it has many red points. Then, why A7 has good roughness result? Because, the paint filled the original pores of the sawplane surface and made it smooth. Because of the same reason, “full red painted” area has small roughness results (Fig. 7).

In addition, A4, A5, A6, A9, A11 and A12 show good roughness results; but when they are considered with the results of image processing, A5 has good results in paint removal, but had some little problem in roughness due to excessive water-jet excavation in some little areas; this problem is a little more emphasized in A8. Two final results could be delineated:

1. When the stone is slightly painted, the best solution is A2. In fact, it can be easily seen how in this the slightly painted part was perfectly cleaned and it shows a roughness similar to

with the original sawplane surface; on the contrary, the area that was strongly painted wasn't fully cleaned.

2. When the stone is strongly painted, the best solution (but not the perfect one from a roughness point of view) is A5.

Considering the results of both Image Analysis and roughness measurements, it can be said that the best combination of operating parameters for graffiti cleaning process by water-jet on this type of marble is: P = 200 MPa, I = 0.5 – 1.0 mm and v_t = 12.0 – 24.5 m/min depending on the intensity of the paint.

4.3 Economic Considerations

We stated the economical features and operational costs of stone surface finishing with water-jet in our previous study in detail [39]; so that, without going into too much detail, it can be said that: considering both technical and economic parameters as the surface finishing velocity, the ownership costs of the plant, the operating costs and labour cost (in the Italian market), we have obtained the total unit cost (C_t) ranging from 18 €/m^2 to 70 €/m^2. The wide range of the total unit cost is mainly tied with both the inter-distance between passes (smaller I value gives higher C_t value) and the travel speed (faster v_t value gives lower C_t value). However, it should be noted that this range matches with the current unit price in Italy for paint removing (50 €/m^2) from paving and cladding.

5. Conclusions

The possible usage of water-jet technology for graffiti cleaning is investigated. Image analysis and roughness test method were used to evaluate the test applications. According to image analysis results, A4, A5 and A8 are the best solutions, meanwhile, according to the roughness measurements, A5 is the best solution. These areas almost refer to the same operational conditions of the water-jet machine. In fact, it is normal not to find exactly the same results both from the image analysis and roughness tests because they are different tests, which have different aspects and have different properties to reveal different features of the cleaning application.

As a result, it can be concluded that cleaning process with water-jet is successful from a technical-economic point of view in the case of saw plane or rustic (i.e. bush-hammered) stone surfaces when a proper combination of water-jet operating parameters is chosen.

It should be pointed out, as a harmfulness, that this study was carried out on one stone type (Carrara Veined marble C), so the optimal operational conditions mentioned here are surely applicable for this stone type. In order to apply a suitable combination of water-jet operating parameters on other lithotypes, extra-experimental test should be carried out in order to assess the effectiveness of the proposed cleaning method.

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Captions

Table 1. Physical and technical properties of Veined marble C.

Table 2. The different operational condition features of the water-jet machine.

Table 3. The colour and statistical values of the painted areas

Table 4. The colour and statistical values of the cleaned areas.

Table 5. Change in colour with cleaning (P-C)

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Figure 1. Microphotographs of Veined marble C in parallel Nicols (a) and crossed Nicols (b).

Figure 2. The methodology followed in this study

Figure 3. A view from the cleaning process by water-jet machine in the test laboratory.

Figure 4. The first marble sample with painted and cleaned areas.

Figure 5. The twin square on the surface are considered to scan and compare.

Figure 6. The sample areas on the marble surface (sample P06).

Figure 7. The square couple on non-painted surface for comparing

Figure 8a. The colour histograms of A5-P and A5-C

Figure 8b. The colour histograms of A10-P and A10-C

Figure 8c. The histograms of the target area and good and bad examples.

Figure 9. The results of roughness analysis carried out on the painted/cleaned samples.

Figure 1
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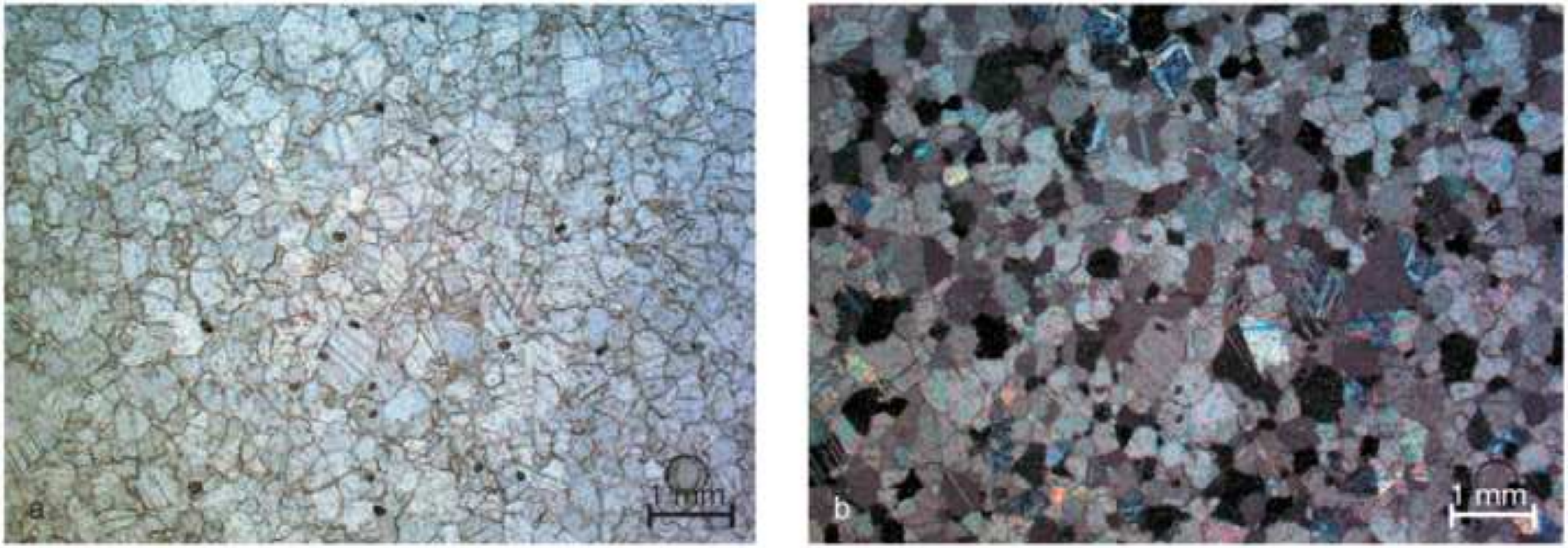

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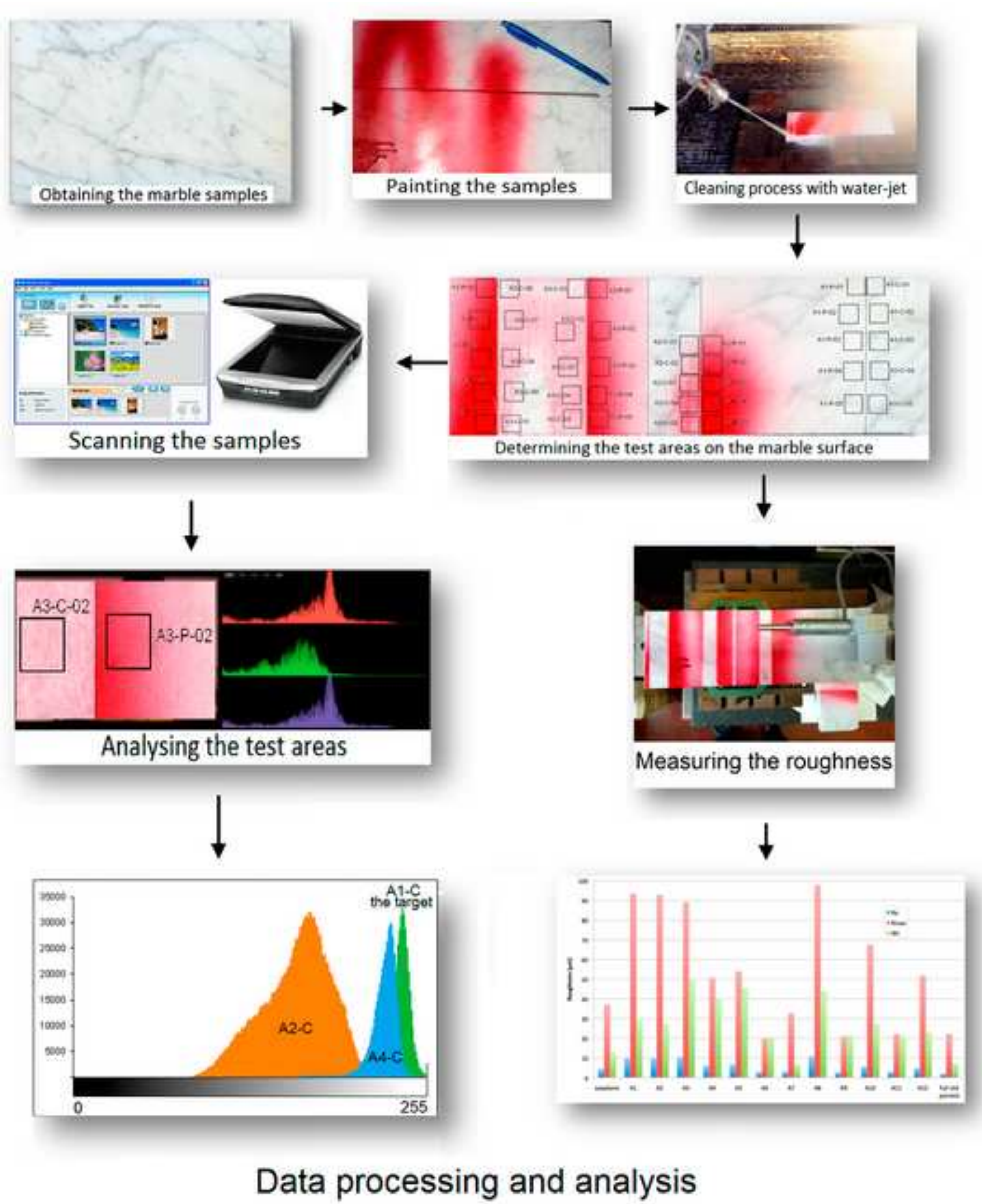

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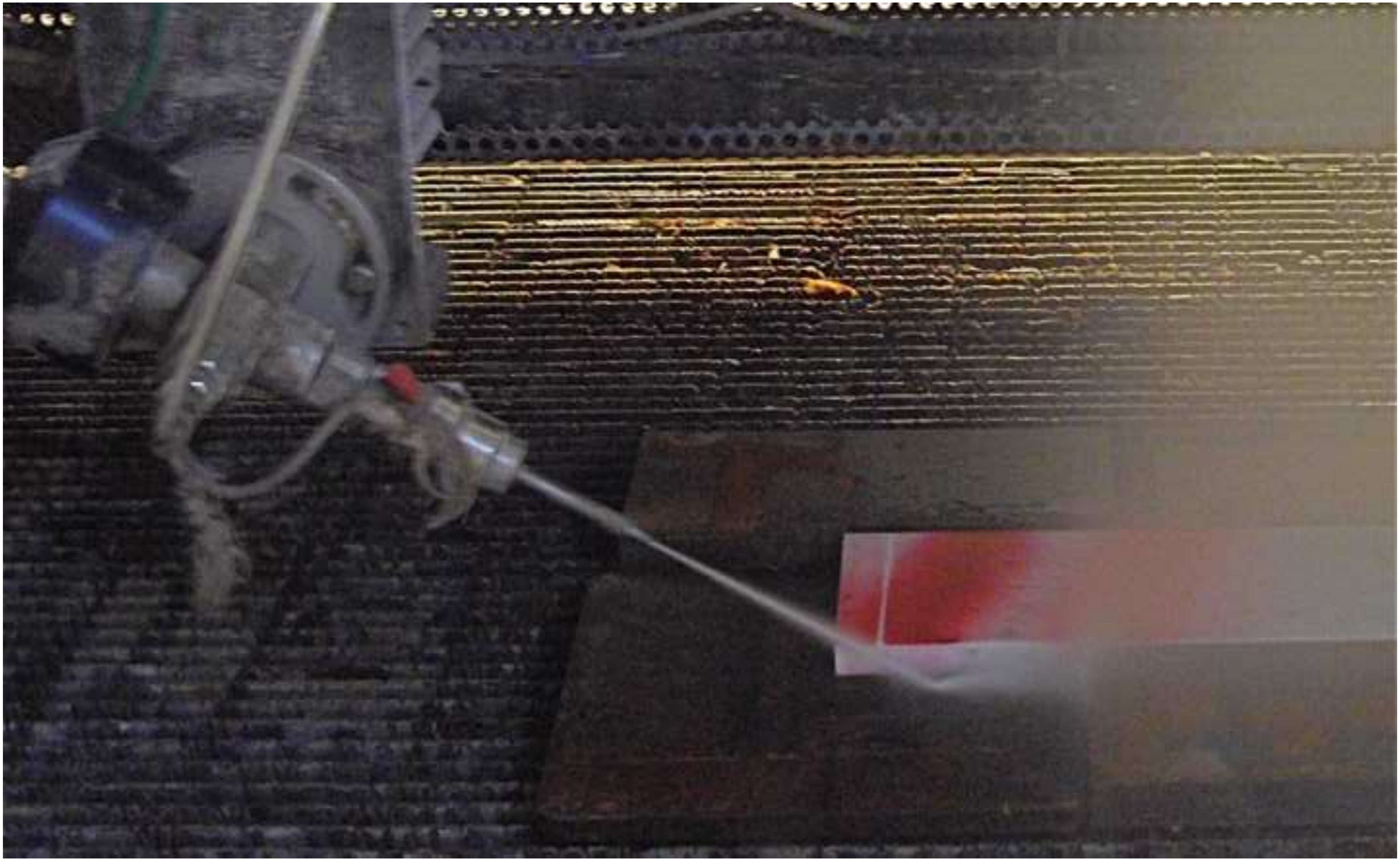

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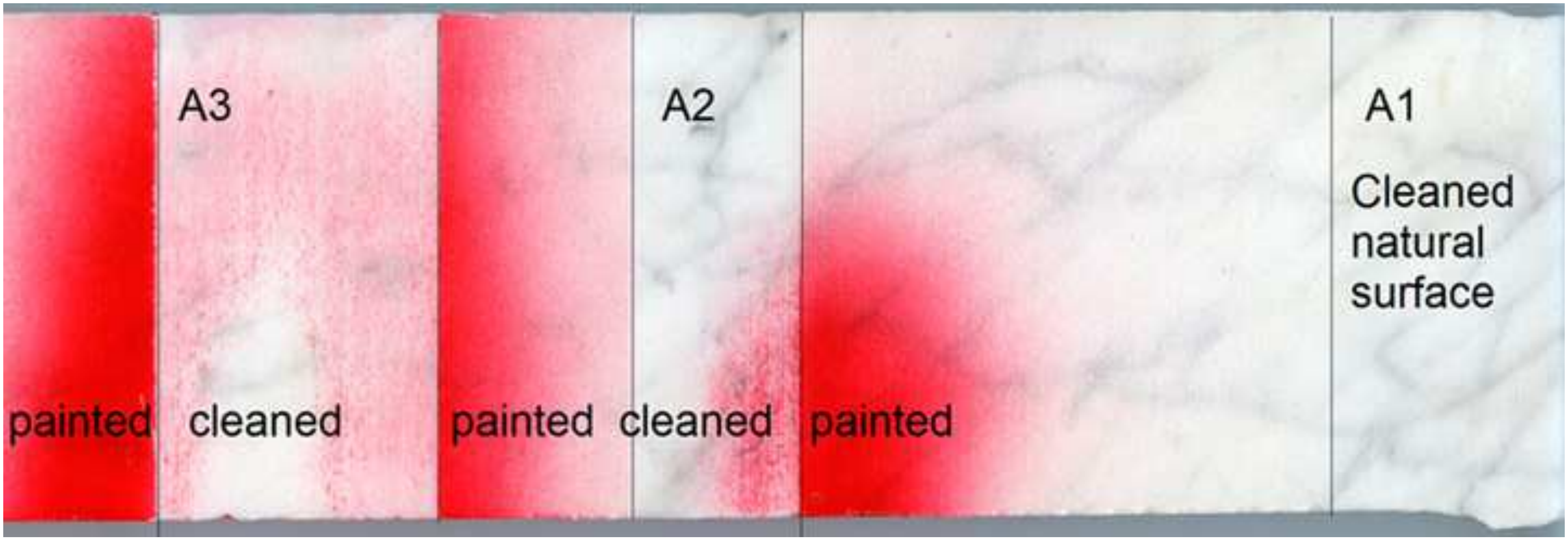

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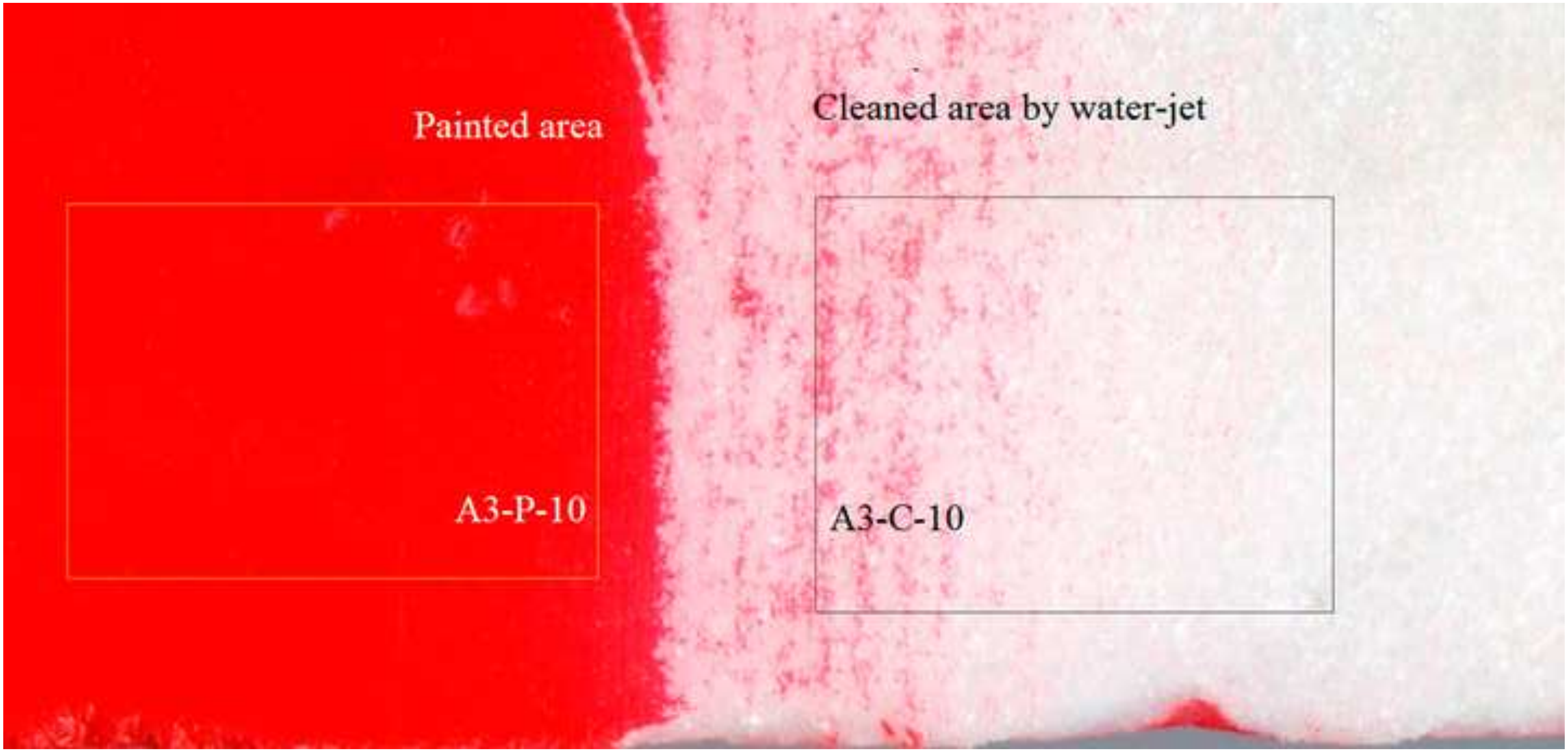

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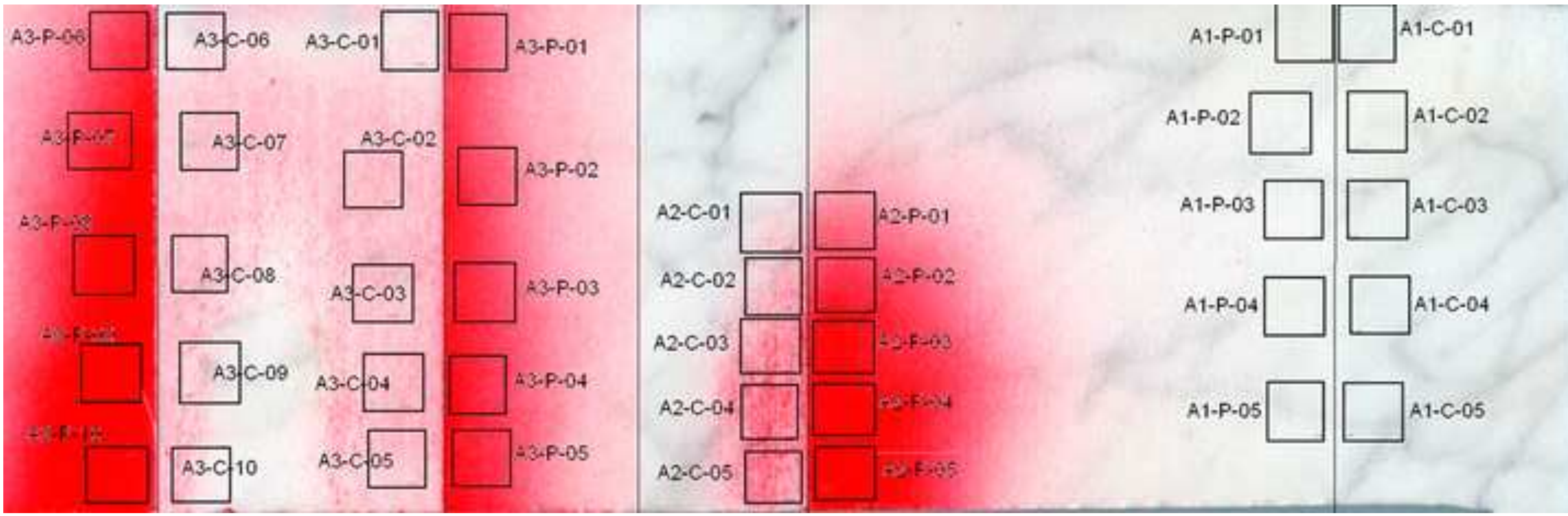

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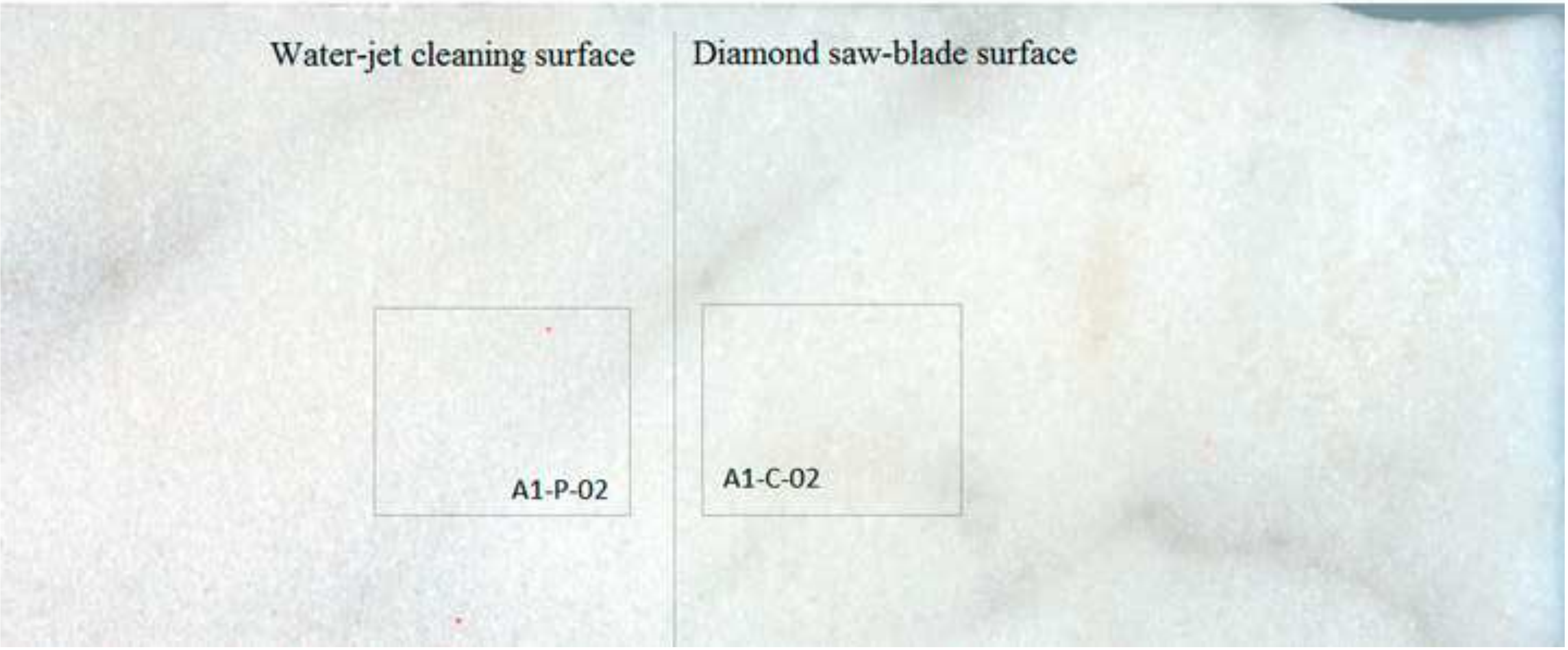

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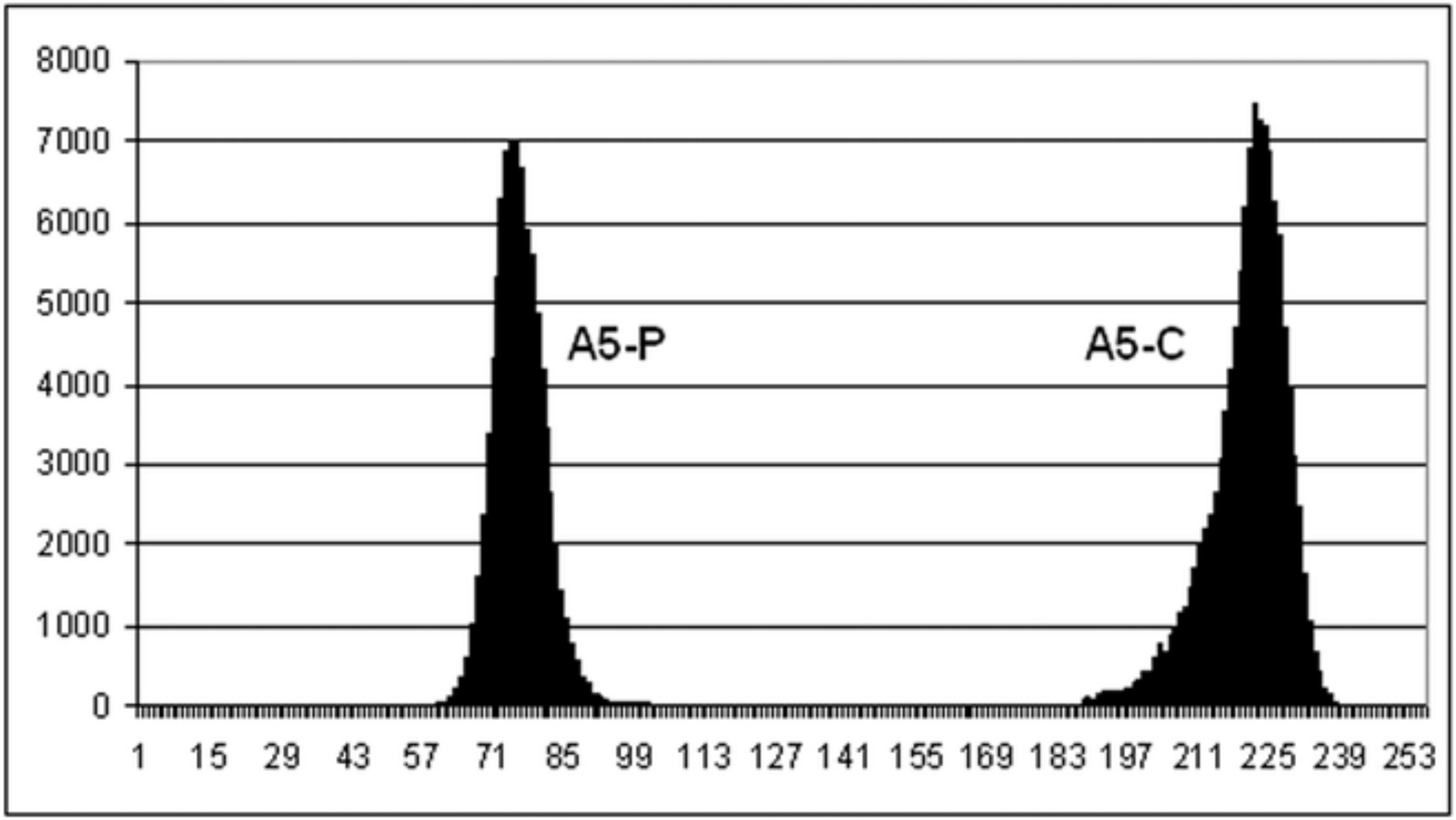

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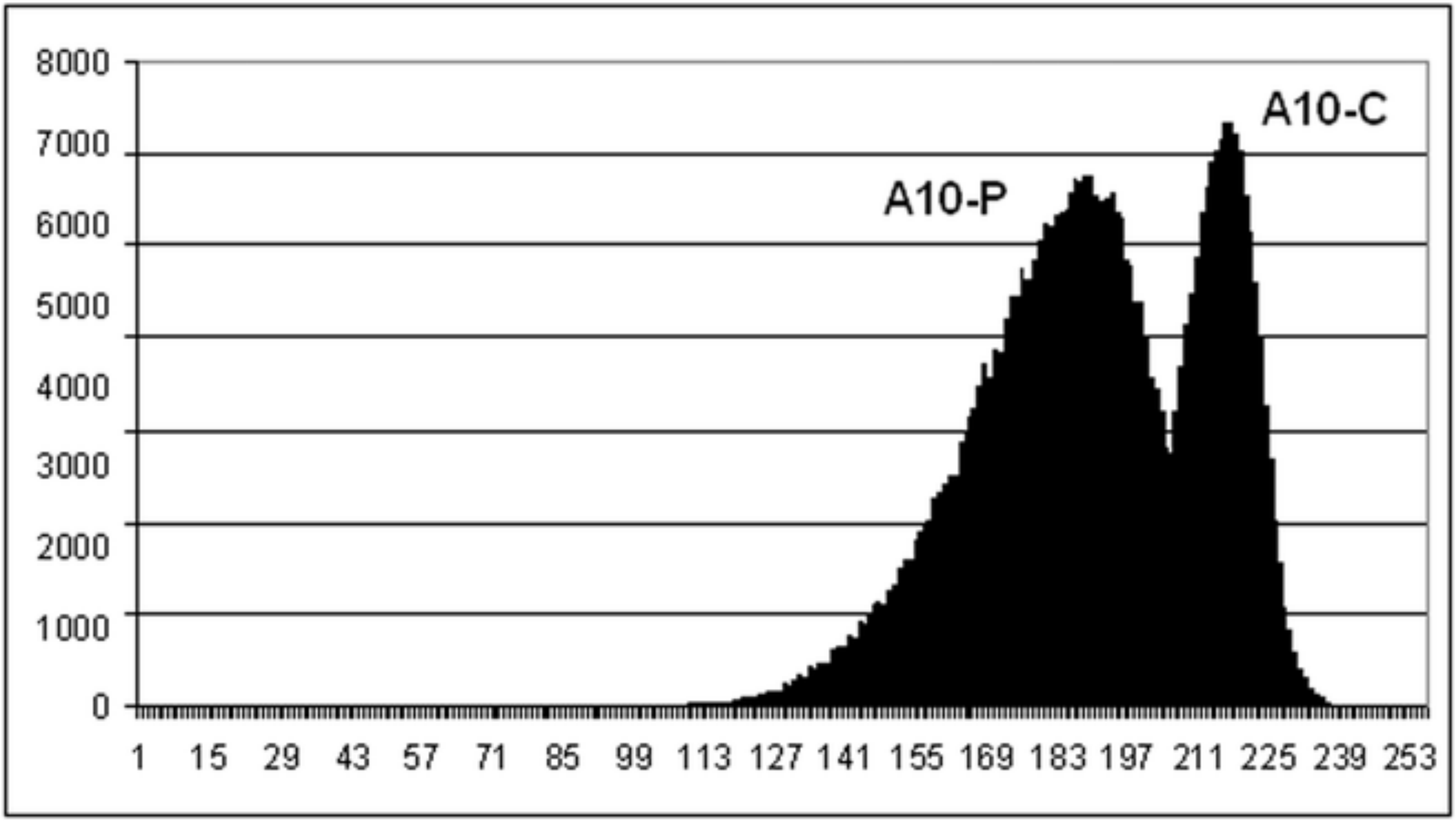

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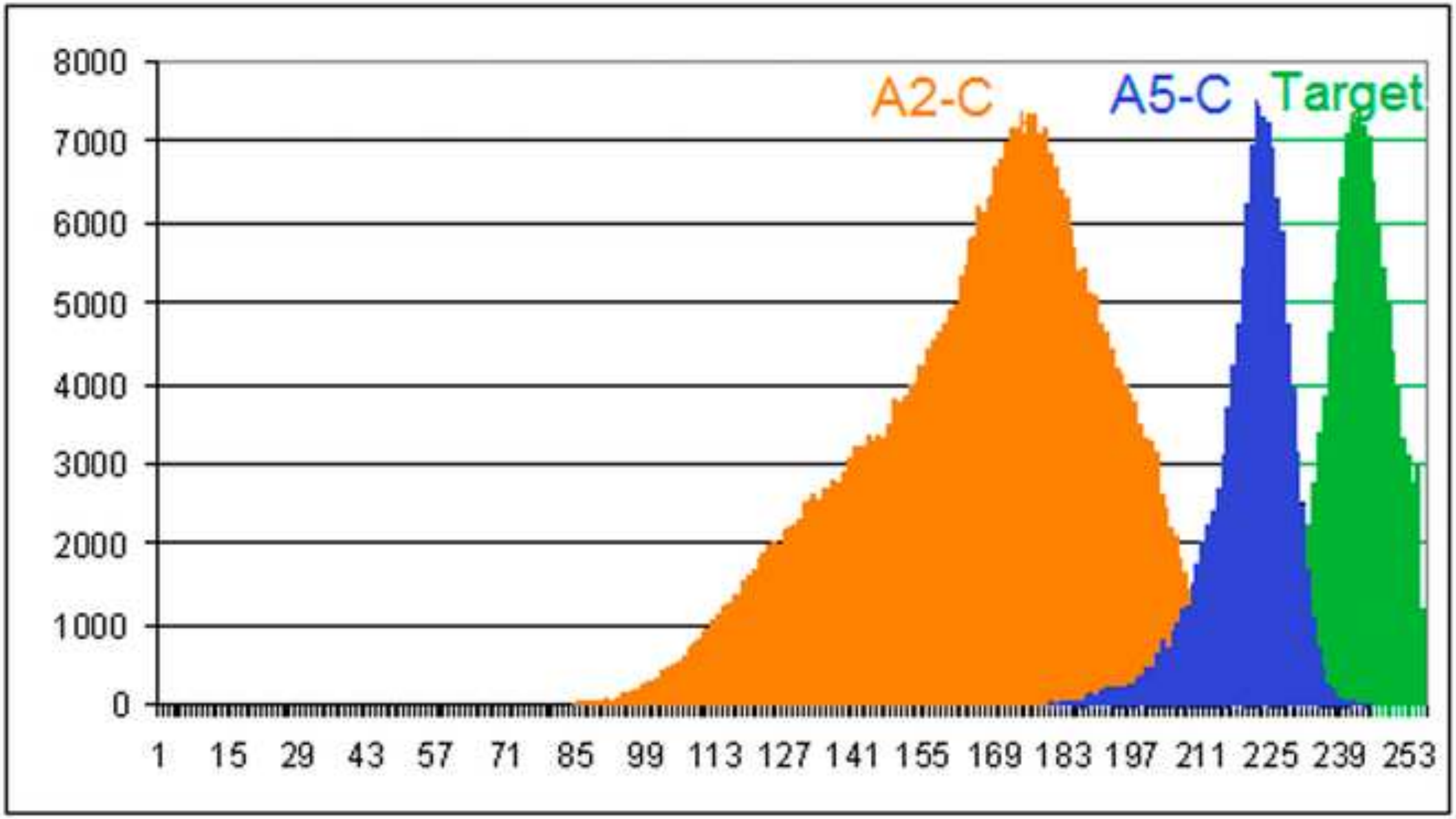

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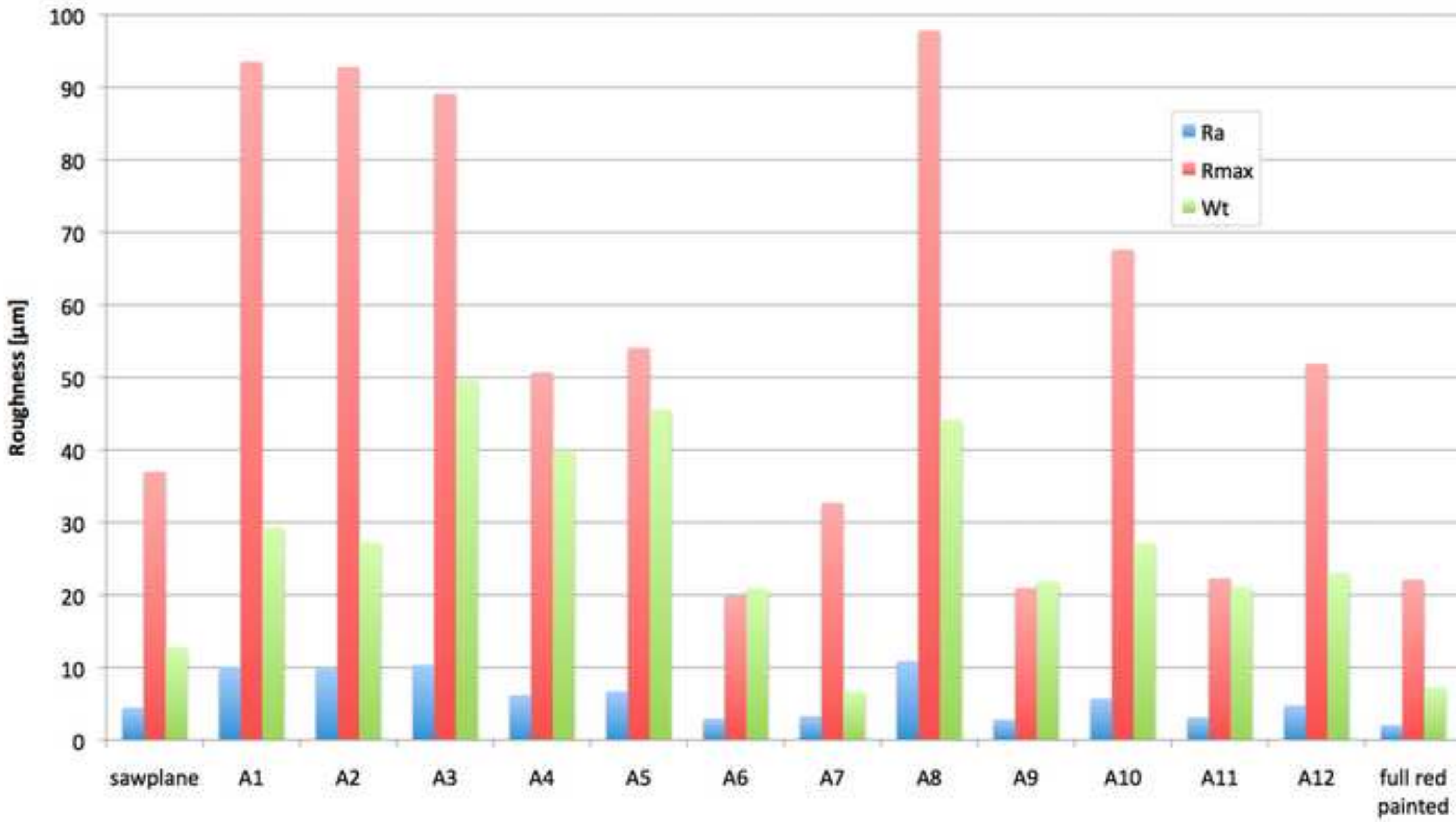

Table 1

Table 1. Physical and technical properties of Veined marble C.

Physical/Technical Property	Unit	Mean
Apparent density (EN 1936)	kg/m^3	2710
Open porosity (EN 1936)	%	0.40
Water absorption at atmospheric pressure (EN 13755)	%	0.12
Water absorption at atmospheric pressure (EN 13755)	MPa	11.6
Flexural strength after exposure to 48 frost cycles (EN 12372 + EN 12371)	MPa	9.6
Uniaxial compressive strength (EN 1926)	MPa	101.4
Slip resistance (honed finishing) – USRV value (EN 14231) (dry)	-	80
Slip resistance (honed finishing) – USRV value (EN 14231) (wet)	-	49

Table 2

Table 2. The different operational condition features of the water-jet machine.

Test ID	***I*** Inter-distance between passes [mm]	***P*** water pressure [MPa]	v_t travel speed [m/min]	**Sample original condition**
A1	1.0	200	24.5	Not painted
A2	1.0	200	24.5	Painted
A3	1.0	200	12.0	Painted
A4	0.5	200	24.5	Painted
A5	0.5	200	12.0	Painted
A6	0.5	100	12.0	Painted
A7	0.5	150	12.0	Painted
A8	0.3	200	24.5	Painted
A9	0.3	150	24.5	Painted
A10	0.3	200	24.5	Painted
A11	0.3	200	24.5	Painted
A12	0.3	200	40.0	Painted

Table 3

Table 3. The colour and statistical values of the painted areas

	Mean	Max	Min	Std. Dev	Coef. Var.	Skewness	Kurtosis
A1-P*	240	255	140	7.3	3.2	-0.8	3.4
A2-P	96	186	49	12.5	24.8	1.1	6.0
A3-P	103	190	52	15.2	26.6	0.8	3.4
A4-P	86	170	50	12.5	29.1	0.7	1.3
A5-P	79	138	48	6.6	19.9	0.3	5.3
A6-P	199	237	121	15.1	7.7	-1.0	1.6
A7-P	113	193	60	20.2	29.8	0.5	0.8
A8-P	95	172	57	11.7	24.6	0.9	2.8
A9-P	82	160	47	9.8	26.8	0.9	4.8
A10-P	124	185	71	13.5	16.0	0.4	1.3
A11-P	133	195	82	14.9	14.3	0.2	0.3
A12-P	128	193	75	11.9	15.2	0.5	3.7
mean	**123**	**190**	**71**	**12.6**	**19.8**	**0.4**	**2.9**

*Diamond saw blade surface (not painted)

Table 4

Table 4. The colour and statistical values of the cleaned areas

	Mean	Max	Min	Std. Dev	Coef. Var.	Skewness	Kurtosis
A1-C**	237	255	196	7.0	2.7	-0.4	0.5
A2-C	178	247	77	22.4	14.4	-0.6	0.5
A3-C	216	254	100	15.3	7.1	-1.1	2.6
A4-C	225	254	132	9.2	4.1	-1.10	4.1
A5-C	223	252	164	8.9	4.2	-0.7	1.2
A6-C	223	223	170	6.7	2.8	-0.7	3.6
A7-C	208	240	149	7.9	3.7	-0.4	0.8
A8-C	223	255	159	7.6	3.5	-0.2	1.3
A9-C	194	241	125	12.3	6.7	-0.3	0.5
A10-C	223	253	158	7.9	3.6	-0.7	1.8
A11-C	212	248	154	8.3	3.9	-0.6	2.4
A12-C	215	249	144	8.8	4.2	-0.6	1.6
mean	**215**	**248**	**144**	**10.2**	**5.1**	**-0.6**	**1.7**

**Water-jet cleaned surface (not painted)

Table 5

Table 5. Change in colour with cleaning (P-C)

	Mean	Max	Min	Std. dev	Coef. var.	Skewness	Kurtosis
A1	3	0	-56	0.3	0.5	-0.5	2.9
A2	-82	-61	-28	-9.9	10.4	1.7	5.5
A3	-113	-64	-48	-0.1	19.5	1.8	0.8
A4	-139	-84	-82	3.3	25.0	1.8	-2.8
A5	-144	-114	-116	-2.4	15.7	1.1	4.0
A6	-24	14	-49	8.4	4.9	-0.3	-2.1
A7	-95	-47	-89	12.3	26.1	0.9	0.0
A8	-128	-83	-102	4.1	21.0	1.1	1.5
A9	-112	-81	-78	-2.5	20.1	1.2	4.2
A10	-99	-68	-87	5.6	12.5	1.1	-0.5
A11	-79	-53	-72	6.6	10.4	0.8	-2.1
A12	-87	-56	-69	3.1	11.0	1.1	2.1
mean	**12**	**-58**	**-73**	**2.4**	**14.8**	**1.0**	**1.1**

Table 6

Table 6. The colour values of non-painted area

	Mean	Max	Min	Std. Dev	Coef. Var.	Skewness	Kurtosis
Diamond-saw blade surface (A1-P)	240	255	140	7.3	3.2	-0.8	3.4
Water-jet cleaned (A1-C)	237	255	196	7.0	2.7	-0.4	0.5

Table 7

Table 7. The difference from the diamond-saw blade surface

	Mean	Max	Min	Std. Dev	Coef. Var.	Skewness	Kurtosis
A1-C	-4	0	56	-0.3	-0.5	0.5	-2.9
A2-C	-62	-8	-64	15.1	11.2	0.2	-2.9
A3-C	-24	-1	-40	8.0	3.9	-0.2	-0.8
A4-C	-15	-1	-8	1.9	0.9	-0.3	0.7
A5-C	-18	-3	24	1.6	1.0	0.1	-2.2
A6-C	-17	-32	30	-0.6	-0.4	0.1	0.2
A7-C	-32	-15	9	0.6	0.5	0.4	-2.6
A8-C	-17	0	18	0.3	0.3	0.6	-2.2
A9-C	-46	-14	-16	5.0	3.5	0.5	-2.9
A10-C	-18	-2	18	0.6	0.4	0.2	-1.6
A11-C	-28	-7	13	1.0	0.7	0.2	-1.0
A12-C	-26	-6	3	1.5	1.0	0.3	-1.9
mean	**-26**	**-7**	**4**	**2.9**	**1.9**	**0.2**	**-1.7**

Table 8

Table 8. The difference from the water-jet cleaned surface

	Mean	Max	Min	Std. Dev	Ceof. Var.	Skewness	Kurtosis
A1-C	-	-	-	-	-	-	-
A2-C	-58	-8	-119	15.4	11.7	-0.2	0.0
A3-C	-20	-1	-96	8.3	4.4	-0.7	2.1
A4-C	-11	-1	-64	2.2	1.4	-0.7	3.6
A5-C	-14	-3	-32	2.0	1.5	-0.4	0.7
A6-C	-13	-32	-25	-0.3	0.2	-0.4	3.2
A7-C	-28	-15	-46	1.0	1.1	-0.1	0.3
A8-C	-13	0	-37	0.6	0.9	0.2	0.8
A9-C	-42	-14	-71	5.3	4.0	0.1	0.0
A10-C	-14	-2	-38	0.9	0.9	-0.3	1.3
A11-C	-24	-7	-42	1.3	1.3	-0.3	1.9
A12-C	-22	-6	-52	1.8	1.5	-0.2	1.1
mean	**-24**	**-8**	**-57**	**3.5**	**2.6**	**-0.3**	**1.4**

Dear Editor,

thank you for having considered our manuscript entitled "**An investigation on the efficiency of water-jet technology for graffiti cleaning"** for publication in *Journal of Cultural Heritage* (ref. no, CULHER-D-15-00271).

Two valuable reviewers had commented the manuscript and we received their comments with your decision. We have been working on it and now, we feel that it is ready for re-submitting.

In a few words, according to the reviewers' comments we have improved both Abstract and Introduction. Moreover, we have also strongly improved the Results and the Conclusions. Finally, we have added new references. Changes in the manuscript are written in red.

Reviewers' suggestions were very useful to our work.

As we wrote in the first Cover Letter, the manuscript describes the trials of the high-pressure water-jet used to remove spray paint from marble surface. Furthermore, this paper has not been published elsewhere.

Cordially yours,
Nicola Careddu, Ph.D.

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Dear Editor,

please find attached our manuscript entitled, "**An investigation on the efficiency of water-jet technology for graffiti cleaning"** to be considered for publication in *Journal of Cultural Heritage*. The paper was written by Dr. Nicola Careddu and Dr. Ozgur Akkoyun.

The number of words contained in the article is 5053 (included abstract and references).

The manuscript describes the trials of the high-pressure water-jet t used to remove spray paint from marble surface. Furthermore, this paper has not been published elsewhere.

We are aware that *Journal of Cultural Heritage* has a very important role in the safeguard and conservation of cultural heritage especially when stone materials are used in buildings/monuments; our manuscript deals with this issue. We would therefore be grateful if you could let us know if this manuscript may be considered for publication.

Cordially yours,
Nicola Careddu, Ph.D.

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