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Original article

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.

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:

- cleaning the spoilt surface, normally using specific solvents or even by means of sand-blasting;
- 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 [4–6]. 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

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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 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 is 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].

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

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 Fig. 1 in both 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 Fig. 2.

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*