STONE SURFACE FINISHING BY PULSATING WATER JETS

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Abstract
A Number of methods of stone surface treatment is currently used to improve the aesthetic appearance of the stone surface or to increase its roughness (reduce its slipperiness). Traditional methods exhibit various disadvantages that reduce the interest of the market. In the paper, results of the research oriented at the evaluation of possibility to use pulsating water jets for ornamental stone surface treatment are presented. Three different types of rocks (granite, basalt, and marble) were exposed to flat pulsating water jets during the tests. Characteristics of rock surfaces created by acting of pulsating water jets were compared to those created by traditional methods, namely polishing, bush hammering and flaming. Results obtained up to now indicate that the application of pulsating water jets in surface treatment of ornamental stones can reduce (or even eliminate) disadvantages of traditional techniques because it creates surface with required roughness but preserves its aesthetical appearance.

Keywords: ornamental stone, pulsating water jet, surface characteristics, surface treatment

1. Introduction

Traditional methods of stone surface processing and finishing include different kinds of treatment applied to improve the aesthetic appearance of the surface and/or to increase its roughness (and thus reduce its slipperiness) (1).
Chiselling represents an impingement treatment consisting in the stone percussion by chisels of different dimensions that produces a sequence of depressed and protruding areas on the surface.
Bush hammering is a rough impingement treatment of the stone surface that can be obtained by “bush hammers” (a particular kind of hammer with a number of pyramidal picks). Bush hammering is used mainly in external applications, such as sculptures, stairs, riddles, and pavements. It gives to the surface a carved aspect, rough and in relief (called “orange skin”).
Hammering is similar to the bush hammering. It is characterized by a less regular surface obtained with a coarser hammer.
Scratching represents by hand surface finishing treatment obtained with hammer and chisel. It is used usually for rough elements on polished or already bush hammered or flamed stone surfaces. Variation of the scratching method with series of streaks as an aesthetical result is called stepping.
Sand blasting consist in the projection of a mixture of water and quartz (or corundum, or glass spheres) sand at high pressure and velocity against the treated surface. Sand blasting is soft and elegant treatment that can be adopted for every kind of material, even in thin slabs (8 mm).
Flaming means heat-treatment obtained through a high temperature flame, produced by single or multiple blowpipes, normally 45° inclined and fed with oxygen (oxidant) and propane (combustible).
Grinding is a shaving treatment that can be obtained using abrasive tools as grinding

wheels, dishes, rollers.

Another type of a shaving treatment is honing. It consists in the levelling of the surface irregularities of sawed material by abrasive wheels applied in a sequence of decreasing abrasive grain size.

Polishing is well known processing which provides shine, mirroring and optimal levelling to the stone surface. It produces a surface which is quasi-impermeable and less vulnerable to external agents both chemical and meteorological.

Water jetting is a relatively new process of stone surface treatment based on the action of very high velocity water jets generated at constant pressure [2, 3]. Considering the surface roughness, the results of water jetting are comparable to the bush hammering or flaming processes, however, water jet treated stone surfaces provide higher level of aesthetical appearance.

All of the described technologies exhibit different disadvantages which reduce for each of them the interest of the market. In case of surface finishing treatments based on the action of mechanical tools, sand blasting and flaming, the technological limits are due to the changes of the surface characteristics of the treated material. The changes are produced by mechanical alterations (as consequence of impingement or of heat shock actions) or chromatic modifications (as an effect of production of micro-cracks) and by crystals melting (which generates a decrease of colours brightness and some chromatic differences with an opaque effect on the material that is not desired by possible end users).

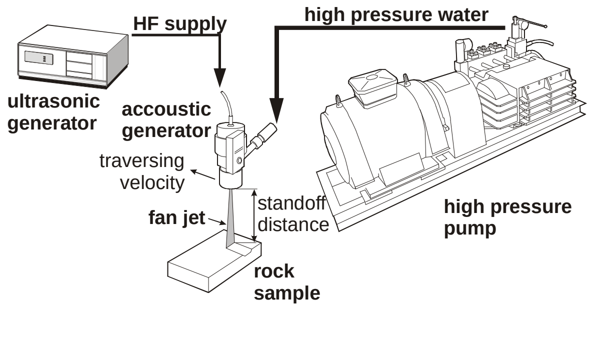

Figure 1. Schematic drawing of the experimental setup.

In the case of polishing, for which the chromatic and aesthetic aspects are preserved, the surface has slippery characteristics which represent a significant disadvantage, especially in case of pavement applications.

Stone surface treatment by water jet technology overcomes some disadvantages, but with a low productivity and high costs. The pressure used for stone surface treatment ranges between 200 and 400 MPa. The problems related to the technology are linked with the very high pressures and correspondingly low flow rates used that generate a small jet impact area. As a result, the technology provides low productivity of surface treatment.

The application of pulsating water jets in ornamental stone surface treatment has the potential to improve the productivity and reduce costs of water jet technology. This is due to the fact that the pulsating water jet technology is based on the dynamic stress action generated on the target material by the short high-pressure transients generated by repeated impact of high-velocity liquid mass on the rock surface. The impact pressure generated in the area by the pulsating jet is about ten times higher than the corresponding stagnation pressure.

In this paper, results of the research oriented at the evaluation of possibility to use pulsating water jets for ornamental stone surface treatment are presented.

2. Experimental procedure

A schematic diagram of experimental setup for exposure of tested rock samples to pulsating high-speed water jet is shown in Fig. 1. Pressurized tap water was supplied from plunger pump (maximum operating pressure 100 MPa, maximum flow rate 130 l min^{-1}) to the acoustic generator of pressure pulsations equipped with the fan jet nozzle. The nozzles with following equivalent diameters and spraying angles were used in experiments: 1.60 mm – 25°, 2.05 mm – 15°, and 3.00 mm – 15°. Two levels of operating pressure (30 and 50 MPa) were selected for the tests. The acoustic generator generated flat pulsating jet that was moved at the constant traversing velocity over the sample. Traversing velocities from 4 to 27 $m\,min^{-1}$ were used in experiments. Standoff distance from the nozzle exit to the sample surface was set to 40 mm at operating pressure of 30 MPa and 50 mm at pressure of 50 MPa, respectively. These standoff distances were determined as optimum in previous tests.

Testing samples were prepared from 300 mm wide and 20 mm thick slabs made of three types of rocks – basalt, granite and marble. Mineral composition, physical and mechanical properties of rock samples are reported in Table 1 [4, 5].

Table 1. Mineral composition, physical and mechanical properties of rock samples.

Characteristics	Granite	Marble	Basalt
Mineral composition			n.a.
Quartz [%]	30.0		
KFeldspar [%]	35.0		
Plagioclase [%]	25.5		
Biotite and others [%]	9.5		
Calcite [%]		100	
Volumic mass [kg/m^3]	2,622	2,720	2,718
Absorption coefficient [%]	0.33	0.096	0.69
Knoop hardness [MPa] (*)	6,128	1,366	5,115
standard deviation [MPa]	1,620	166	1,258
Compressive strength [MPa]	165	128	257
Flexural strength [MPa]	15.6	20.2	40.2
Impact test [cm]	58	75	89
Abrasion resist.ce [mm/km]	2.32	0.32	1.19

(*) Weighted average of the hardness of the various mineral components.

Surfaces created by the flat pulsating jet were evaluated in terms of preserving of the aesthetical appearance of the stone and compared to those created by polishing, soft and hard bush hammering, flaming, and by high-speed continuous water jets. Subsequently, surface characteristics of the surfaces were determined.

2.1 Acoustic generator of pressure pulsations

A special method of the generation of the pulsating liquid jet was recently developed and tested extensively under the laboratory conditions at the Institute of Geonics ASCR, v.v.i. in Ostrava. The method is based on the generation of acoustic waves by the action of the acoustic transducer on the pressure liquid and their transmission via pressure system to the nozzle. Schematic drawing of the acoustic generator is shown in Fig. 2, Foldyna and Švehla [6] provide detailed description of the acoustic generator. Acoustic generator of pressure pulsations used in experiments generated pressure pulsations at the frequency of about 20 kHz (exact frequency depends on the actual geometrical configuration of the generator), amplitude of vibrations of the acoustic transducer was set to 7 µm.

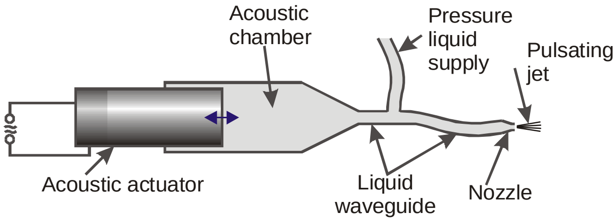

Figure 2. Schematic drawing of the high-pressure system with integrated acoustic generator of pressure pulsations.

2.2. Characteristics of created surface

The confocal laser scanning microscope was used for determining basic characteristics of studied surfaces. The tiling 3D images were acquired by composition of 5 x 5 rectangular microscopic fields in confocal scanning mode. Sizes of individual microscopic fields were 2560 x 1920 µm.

Then the surface roughness analysis mode was used to determine values of arithmetic mean roughness (SRa) and average maximum height roughness (SRz). Measured values should be considered as rough ones due to the data compression (and thus also simplification of the surface structure) during the process of the large tiling image composition. However, all images were acquired by the same procedure and they can be used for the purpose of comparison of studied surfaces.

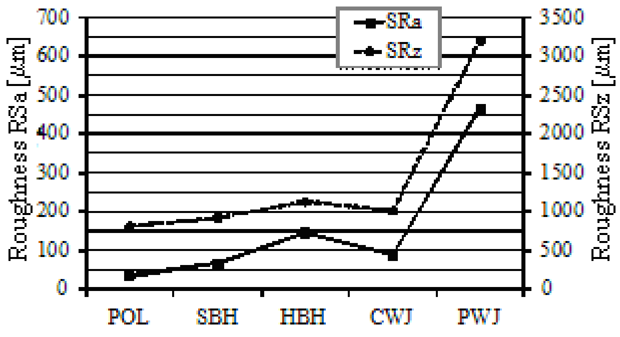

Figure 3. Results of surface roughness analysis of basalt surface treated by polishing (POL), soft bush hammering (SBH), hard bush hammering (HBH), continuous water jet (CWJ) and pulsating water jet (PWJ).

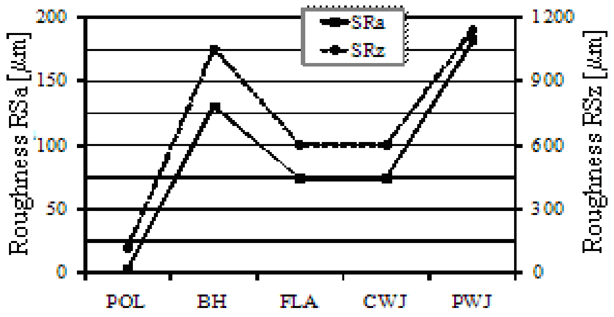

Figure 4. Results of surface roughness analysis of granite surface treated by polishing (POL), bush hammering (BH), flaming (FLA), continuous water jet (CWJ) and pulsating water jet (PWJ).

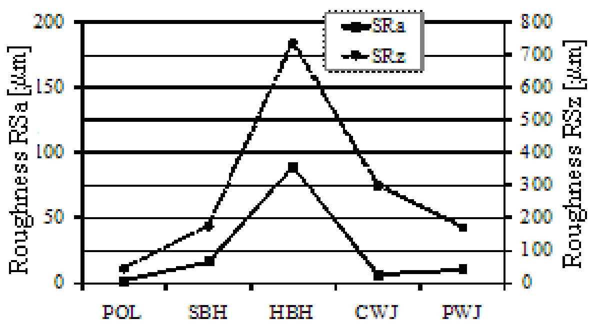

Figure 5. Results of surface roughness analysis of marble surface treated by polishing (POL), soft bush hammering (SBH), hard bush hammering (HBH), continuous water jet (CWJ) and pulsating water jet (PWJ).

3. Results and discussion

As previously mentioned, the results of the studied process are represented by the surface roughness and aesthetic appearance obtained.
As shown in Figure 3 for the basalt sample, the parameters characterising the roughness are higher in case of application of pulsating jet technology. It is to be outlined that the flexibility of the technology, due to the number of operative parameters that can be differently adjusted, can lead to a modulation of the surface roughness obtainable to fulfil the end users requirements. The feature represents a substantial advantage considering that the production rate can be consequently modified and kept at the requested industrial level.
The same kind of results were obtained for granite (Figure 4), while in case of marble the application of the new technology is compatible only for low values of roughness (Figure 5). In fact, for rougher treatments the marble surface suffers a reduction of the aesthetical appearance.
Figure 6 illustrates the chromatic appearance of surfaces of three types of ornamental stones treated by various methods of stone surface processing. The evaluation of chromatic appearance of the treated surface is not easy. A number of methods have been developed to quantify the effect of different technologies on the surfaces appearance, but no one gave a complete satisfactory solution.
In Figure 7 the gray tone and its medium variance are reported for different treatment technologies applied to basalt, granite and marble. The data reported in that graph should be read differently according to the rock characteristics.
In case of basalt and marble, the natural structure of the rock, from the chromatic point of view, is quite uniform and if the maintaining of that structure is considered a positive result, the performance of an effective treatment should lead to a low value of the medium variance. According that statement, the pulsating jet technology

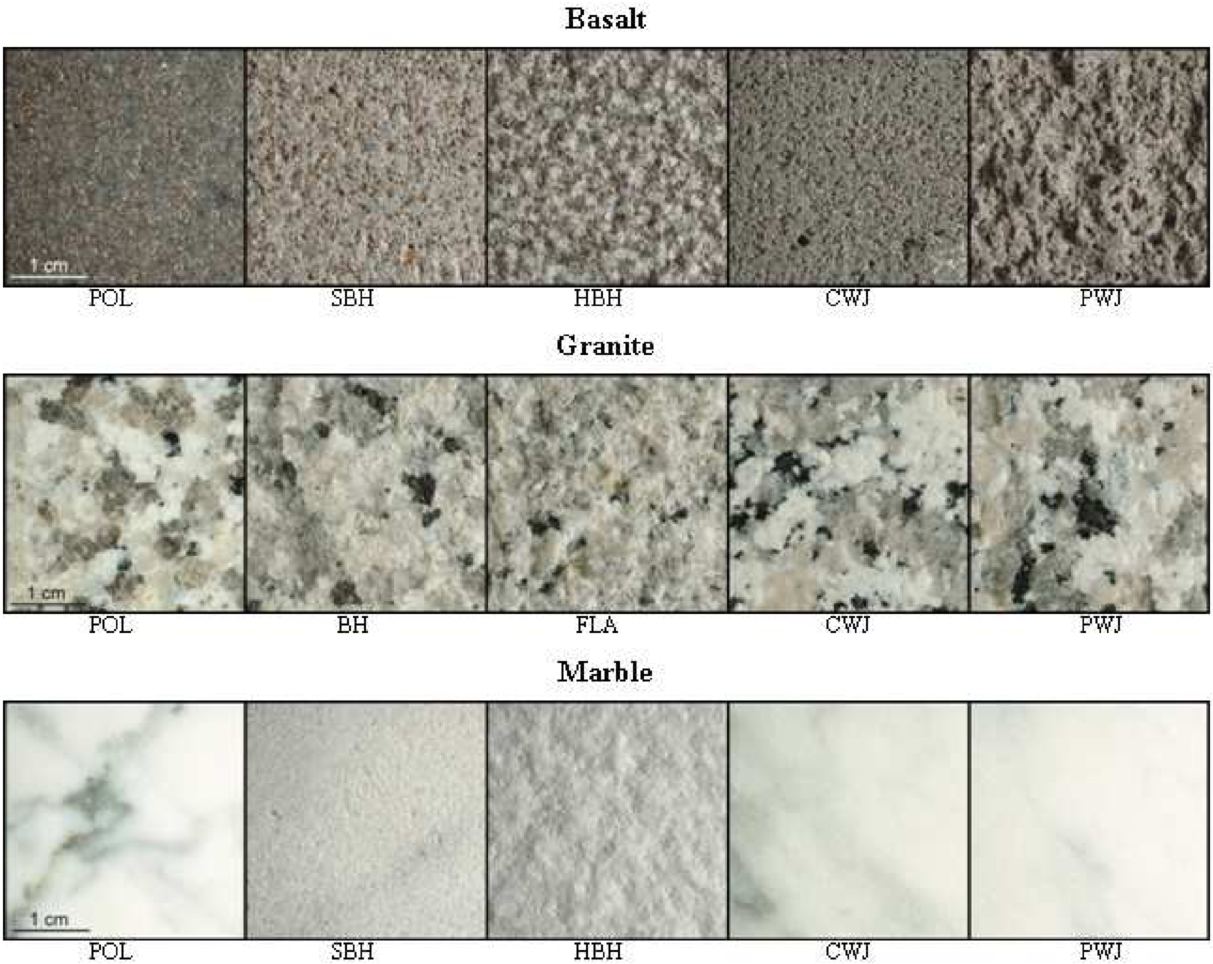

Figure 6. Photomacrographs of treated surfaces: POL - polishing; BH - bush hammering; SBH - soft bush hammering; HBH - hard bush hammering; FLA - flaming; CWJ - continuous water jet; PWJ - pulsating water jet.

treatment produces a surface which is to be considered better than the corresponding surface relative to the other technologies (soft

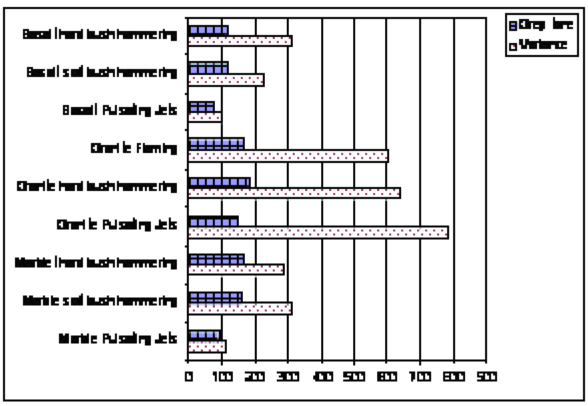

Figure 7. Grey tone and medium variance for different surface treatment technologies applied to basalt, granite and marble.

and hard bush hammering), as the results reported in Figure 7 show for both basalt and marble.

In case of granite the situation is opposite. The natural chromatic structure is not-homogeneous and an efficient treatment should lead to a high value of mean variance, witness of a unchanged conditions. Again the graph of Figure 7 show that from this point of view the pulsating jet technology is more efficient than bush hammering and flaming technology.

The experimental results have shown that the pulsating jet technology is competitive even when the productive aspects are considered.

In fact the production rate obtained for the different rocks during the tests are comparable to that obtained in the industrial application of traditional technologies.

4. Conclusions

Three different types of rocks (granite, basalt, and marble) were exposed to flat pulsating water jets during the tests. Characteristics of rock surfaces created by acting of pulsating water jets were compared to those created by traditional methods, namely polishing, bush hammering and flaming. Results obtained up to now indicate that the application of pulsating water jets in surface treatment of ornamental stones can reduce (or even eliminate) disadvantages of traditional techniques because it creates surface with required roughness but preserves its aesthetical appearance. The great advantage of the technology represented by the use of relatively low operating pressures is confirmed.

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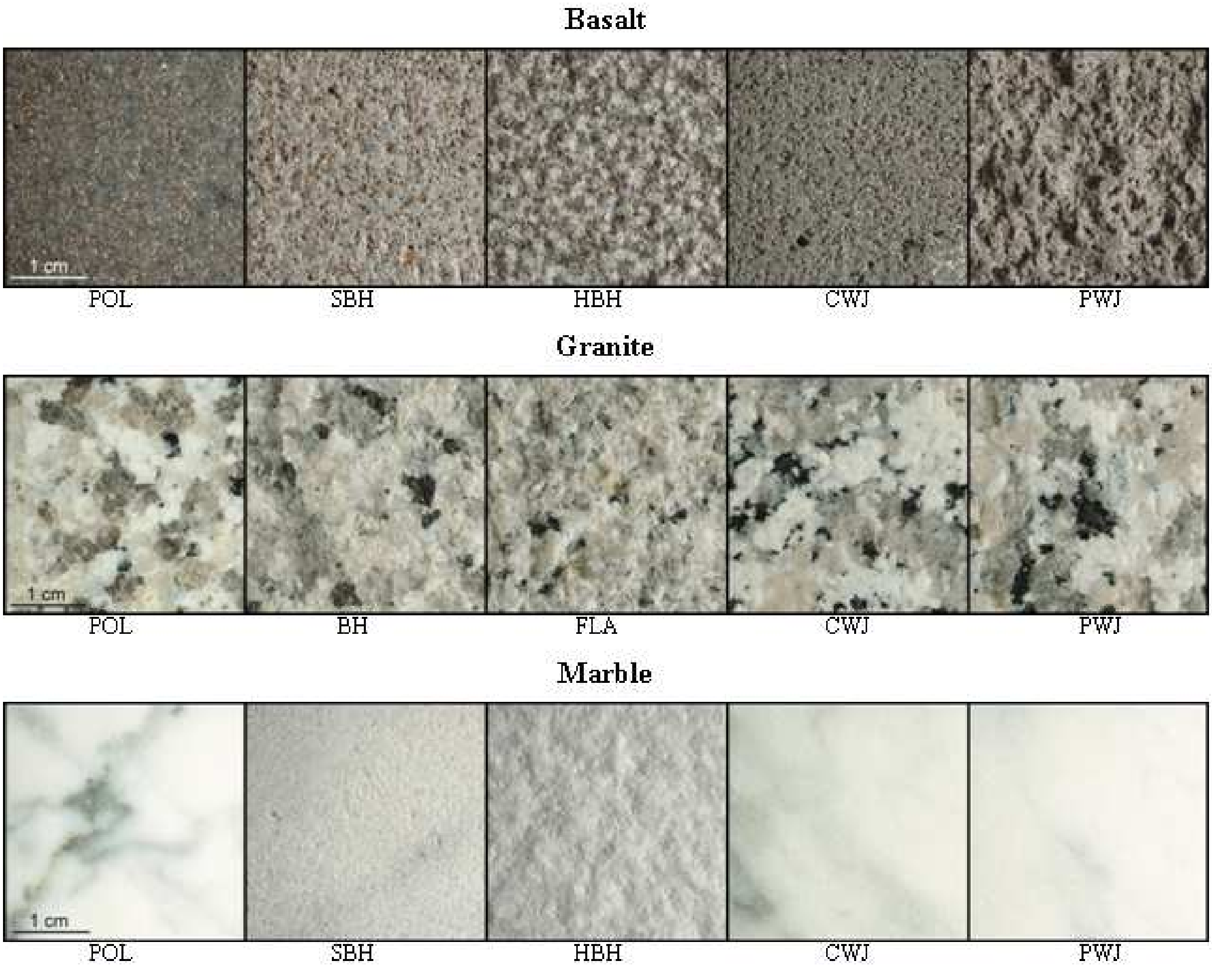

Figure 6. *Photomacrographs of treated surfaces: POL - polishing; BH - bush hammering; SBH - soft bush hammering; HBH - hard bush hammering; FLA - flaming; CWJ - continuous water jet; PWJ - pulsating water jet.*