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Laser surface texturing of granite

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Abstract

Presence of contaminants on surfaces becomes a significant problem both in industry and at home. Small particles or bacteria adhered to surfaces of domestic kitchens are not easily removed by regular cleaning procedures. The effect of substratum wettability upon contaminants adhesion has been known for a long time. The phenomenon of surface cleaning is closely related to morphology, and chemistry of surfaces. These characteristics can be modified by subjecting materials to surface treatments. One of the most promising techniques aiming to modify surface features is the laser texturing. In such a way, it is possible to achieve the surface properties leading to the desired wettability in an accurate manner, and with minor contamination. In this work, the wetting features of Zimbabwe black granite, a middle-to-fine-grained natural stone commonly employed as countertops in kitchens and bathrooms, are modified by laser surface texturing. The main aim is to increase its hydrophobic degree so as to reduce the attachment of contaminants on the surface. For such purpose, two laser sources (λ = 1064 and 532 nm) were employed. The influence of different laser processing parameters on surface characteristics (wettability, roughness, and chemistry) of granite was statistically assessed. The morphology resulted from the laser surface texturing was found to be the principal phenomenon governing the wettability modifications, as the chemical composition remained virtually unaltered after treatment.

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Keywords: Natural stone; laser texturing; wettability; contact angle.

1. Introduction

Among the wide range of natural used currently in construction industry granite represents the greatest part of the production [1]. This is a crystalline igneous rock composed essentially of quartz, feldspars and mica. Its use as building material is not only restricted for outdoor constructions but also for countertops in the domestic environment, such as kitchens and bathrooms. In this case, surface contamination due to the presence of bacteria may result in disease transmission [2, 3]. The contamination is a superficial problem that depends to a large extent of the wettability of the surface because this parameter controls the microbacterial adhesion [4]. The correlation between the degree of wettability of a substrate and the number of microbial cells attached has been already established, resulting in an inversely proportional relationship between them [5]. Several authors have establish that by means of the use of superhidrophobics surfaces the elimination of the superficial contamination can be achieved by means of the self-cleaning phenomenom [6, 7]. This phenomenon, observed in hydrophobic surfaces, is based on the rolling of the liquid droplets which trap contaminant particles along the surface leading to the remove of the undesirable contamination [8]. Laser surface texturing is a well-known method to modify the wettability of a great range of materials [9–12]. Furthermore, it offers advantages

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over other chemical techniques (e.g. silanization of post-textured surfaces) [13], such as its higher processing rate, due to the fact that there is no need to use prior or subsequent coatings [14, 15]. Also, the laser treated resulting surface is free of contaminants without change in the bulk properties of the material, fact that adds value to this technique. The laser texturing can be applied to different materials because of is based on the absorption of the radiation by the matter [16, 17, 18], but is not have been applied to natural stones yet.

In the present paper, laser surface texturing of Zimbabwe black granite is analysed. The effect of the laser processing parameters on the wettability and surface roughness was performed for two different wavelengths (λ = 1064 and 532 nm). The aim of this work is the study of the processing parameters on the wettability and roughness of granite with the aim to obtain hydrophobic granite surfaces. This will make possible the control of contaminants and the presence of bacteria on the surface of these materials. The influence of the laser processing parameters (laser power, scanning speed, pulse frequency and spot overlapping) on the treated surfaces of granite was analysed by means of statistically planed experiments.

2. Materials and methods

2.1. Material

Square polished slabs of dimensions 5 cm x 5 cm x 2 cm (length, width and height) of Zimbabwe black granite were used as base material in the experiments. This middle-to-fine grained natural stone belongs to the family of igneous rocks and it is characterized by exhibiting a deep black appearance and small bright areas due to the presence of quartz in its morphology. It is principally composed of quartz, calcium-rich plagioclase feldspar and orthopyroxenes, and also presents small proportions of biotite and diopsides.

2.2. Experimental set-up

Laser surface treatments were performed using a diode end-pumped Nd:YVO_4 (Rofin-Sinar PowerLine E) emitting in TEM_{00} laser beam mode at two different wavelengths; 1064 (M^2 < 1.3 and 20 ns of pulse duration) and 532 nm (M^2 < 1.5 and 14 ns of pulse duration). In both cases, the laser beam was focused onto de surface of the workpiece through F-Theta lens of 211 mm (λ=1064 nm, spot size = 70 µm) and 365 mm (λ=532 nm, spot size = 60 µm). Moreover, laser surface treatments were performed in air at atmospheric pressure. In order to obtain the key processing parameters, that statistically influence (*p-value* < 0.05), a 2^4 Full Factorial Design (FFD) of experiments was elaborated on the dependent response variables: average roughness of the treated areas and the water contact angle. The laser power (*P*), scanning speed (*v*), pulse frequency (*f*) and pass overlapping (*s*) were the selected processing parameters in this case of study [11]. The laser processing parameters (with high "+" and low "-" levels) are show in Table 1. An analysis of the variance (ANOVA) was performed to find out which are the most statistically significant factors on the response variables. Then, a linear regression model was calculated to determine a statistical model between the response variables.

Table 1. Key factors with corresponding levels for the 2^4 Full Factorial Design.

λ (nm)	Laser Power P (W)		Scanning speed v (mm/s)		Pulse frequency f (kHz)		Overlapping s (%)	
	-	+	-	+	-	+	-	+
1064	1.5	3.3	1	20	20	30	0	50
532	0.8	1.4	1	20	20	30	0	50

2.3. Sample characterization

The surfaces of the laser treated samples were inspected in frontal view to the laser treated area by a Phillips XL-30 scanning electron microscope (SEM) system equipped with an energy dispersive X-ray spectroscope (EDS EDAX PV9760) in order to obtain the semi-quantitative chemical composition. Moreover, selected samples were analysed by means of X-ray Diffraction (XRD) using a SIEMENS D-500 diffractometer to determinate structural changes in the surface of the samples. Also, a Bruker Dektak XT surface profiler was used to obtain the surface morphology of the selected treated areas, by means of 2D height-maps, to evaluate the effect of different treatments on the surface damage of the samples.

The average roughness value (*Ra*) of the treated areas was obtained by the mean value of 5 measurements in each treated area, obtained by means of a TESA-Rugosurf 10G surface profilometer.

The water contact angle (θ) was measured using distilled water by means of the sessile drop technique according to the recommendations given by the UNE-EN 828:2013 standard.