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Research Article

Investigation of the Effects of Marble Material Properties on the Surface Quality

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This study aims to investigate the effects of material properties of marble on surface roughness and glossiness. For this purpose, four types of limestones were investigated. Physicomechanical properties of samples were determined through laboratory measurements. Mineralogical and petrographical characterizations were made using thin-section analysis. X-ray fluorescence (XRF) semiquantitative method was used for chemical analysis. Six different grinding-polishing tests for each marble unit were done under fixed operational conditions using the same abrasive series. Relationship between the material properties and the surface quality was investigated. Although the polishing-grinding tests were conducted under the same operational conditions, different levels of roughness and glossiness were observed on different samples. Data obtained from the study proved that the main cause of this difference is textural and chemical composition variations of the marble specimen. Moreover, statistical evaluations showed that porosity, uniaxial compressive strength, and indirect tensile strength have strong effects on the surface roughness and glossiness of the marble specimen. The presence of an inverse relationship between the glossiness and roughness levels was determined as the result of this study as well.

1. Introduction

Marble is an extremely popular ornamental stone for architectural and sculptural purposes. It also has a high potential of taking a polish. Grinding and polishing processes are generally used as the finishing process to obtain polished surfaces which are widely preferred in the global market for decorative purposes due to the pleasing appearance they present [1]. The parameters affecting the efficiency of grinding and polishing processes have been widely investigated in previous studies; however, it is still not understood exactly how the parameters affect the final polish [2]. The effects of material properties on surface quality were investigated by Erdoğan [3], and factors such as porosity, distinct crystal boundaries, cleavages, fillings in the microfractures, and obliqueness between the crystal orientation and the cutting plane were found to be adversely affecting the surface quality. Görgülü and Ceylanoğlu [4] investigated the effects of diamond and SiC abrasives on the surface quality and discovered that surface roughness and glossiness of the stone samples they examined were independent of the abrasive type used. For that reason, the importance of choosing the appropriate series of abrasives and adjusting operational conditions specifically for the stone properties to achieve the desired surface quality was emphasized. The microstructure detection of a glossy granite surface at each separate stage ranging from sawing to grinding was studied by Huang et al. [5]. They concluded that the highest glossiness surface of the workpiece was also the lowest roughness surface which was shaped by diamond grinding in the ductile mode. Ersoy and Kose [6] investigated the relationship between polishing ease and mechanical properties of marble. Their research showed that the strength to wear by friction affects the brightness in marbles, and there is an inverse relationship between the brightness and the abrasion index.

Yavuz et al. [7] examined the effects of belt speed on surface quality by performing polishing tests at various constant rotational speed values and pressure levels of the polishing head. According to the data obtained, optimum polishing quality conditions were met at the belt speed value of 1.3 m/min. Karaca [2] studied the relationship between mechanical properties and the surface roughness of true marble samples and found that there are significant correlations between uniaxial compressive strength, tensile strength, and the surface roughness of the marble specimens. It has not been clearly demonstrated whether the value of the Böhme abrasion loss correlates with the polished marble surface roughness. Gürcan et al. [8] emphasized that different microroughness levels and gloss values were observed due to the different textures and chemical compositions of marble samples studied. Ersoy et al. [9] investigated the effect of abrasive head rotation on the surface quality and revealed that smoother and brighter surfaces are obtained by increasing the abrasive head's rotational speed.

The main objective of this study is to determine the effects of physicomechanical and mineralogical-petrographical properties and chemical contents of limestones on their final glossiness and roughness values. To that end, physicomechanical properties such as unit weight (UW), porosity (P), uniaxial compressive strength (UCS), flexural strength (FS), indirect tensile strength (ITS), Böhme abrasion resistance (BAR), and Schmidt hardness (SH) were determined first. Mineralogical-petrographical characterizations of the samples were done using thin-section analysis, and chemical content of samples was determined by the application of XRF semiquantitative method. Then, polishing tests were conducted, and surface roughness and glossiness of marble strips were measured. Finally, interpreting the obtained data, the effect of material properties on surface quality of marble specimen was determined.

2. Materials and Experimental Procedure

2.1. Determining Material Properties. To determine the physicomechanical properties of the selected marble samples, workpieces were prepared and UW, P, UCS, SH, and ITS tests were conducted according to ISRM [10] standards, whereas FS and BAR tests were conducted according to TS 699 [11]. Thin sections of marble samples were analyzed for mineralogical-petrographical characterizations.

2.2. Polishing Tests. Polishing tests were carried out by using a laboratory-scaled polishing machine designed to be similar to an industrial-scaled machine, equipped with a conveyor belt of 60 cm width and four polishing heads of 35 cm diameter (Figure 1). An abrasive series consisting of 60, 80, 120, 180, 220, 280, 320, 380, 600, and 800, 5 Extra, and a felt pad (Pulitore) were used. The workpieces were obtained from a marble processing plant and were calibrated with diamond abrasives in dimensions of 500 mm long, 300 mm wide, and 20 mm thick. Ten points were marked on the edges of the strips to ensure that the roughness and glossiness measurements were taken from the same points for all samples. Operational polishing machine variables such as belt speed and rotational speed of the polishing head were fixed at 1.48 m/min and 499.5 rpm, respectively. Pressure of the polishing head was kept at 1.25 bar for 60–800 numbered abrasives and reduced to 1 bar for 5 Extra and Pulitore cases. 60 numbered five abrasives were mounted on a grinding head, and six separate polishing tests were conducted for each marble unit by using only one polishing head. After the polishing stage, a compressor was used to blow off the dust and the water drops remaining on the surface of the strips.

Figure 1: Laboratory-scaled polishing machine.

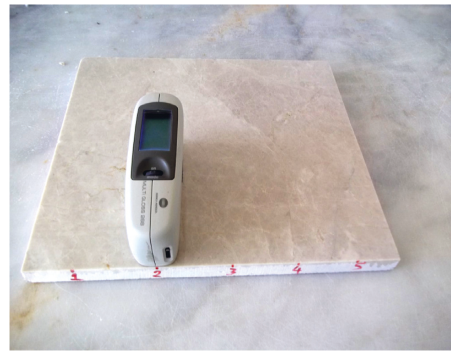
2.3. Surface Quality Measurements. To determine the surface quality of the strips, roughness and glossiness measurements were taken. Taylor Hobson Surtronic 3+ portable surface roughness tester and Konica Minolta Multigloss 268 glossmeter are shown in Figure 2, respectively. The roughness values were measured in terms of the most commonly used parameter "R_a," and the glossiness values were evaluated for a 60° angle and a 9×15 mm area. Arithmetic mean of ten measurements was calculated, and surface profiles of the strips were determined after all six polishing tests were carried out. The same procedure was repeated for the rest of the abrasive series, and the final surface quality of the strips was assessed after Pulitore was used for each marble unit.

3. Results and Discussion

The results of the laboratory measurements and the chemical content of the workpieces are presented in Tables 1 and 2, respectively [1]. Mineralogical and petrographical characterizations of marble samples are given in Table 3 [1].

The average roughness and glossiness values obtained from the six polishing tests versus abrasive numbers for each marble unit are given in Figure 3. It is seen from Figure 3 that roughness values follow an exponentially decreasing trend towards the end of the abrasive series, while it is exponentially increasing for glossiness values for the majority of the surface finish operations as expected [2, 4, 5, 7, 8]. It is clear that small abrasive numbers 60, 80, and 120 with coarse abrasive grains have a more prominent effect on the decrease

(a)



(b)

Figure 2: Measurement of (a) surface roughness and (b) glossiness.

Table 1: Results of physicomechanical tests.

Marble unit	UW (kN/m³)	P (%)	UCS (MPa)	FS (MPa)	ITS (MPa)	BAR (cm^3/50 cm^2)	SH
Adara	25.7	0.39	77.9	15.01	7.53	15.76	39.2
Emperador	25.8	1.85	61.69	13.44	7.23	18.79	41.2
Crema nera	26.59	0.34	83.99	12.9	8.6	15.41	43.6
Sand wave	27.08	1.46	72.05	8.96	7.35	7.95	40

Unit weight (UW), porosity (P), uniaxial compressive strength (UCS), flexural strength (FS), indirect tensile strength (ITS), Böhme abrasion resistance (BAR), and Schmidt hardness (SH).

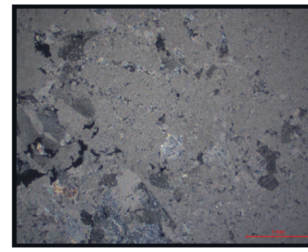
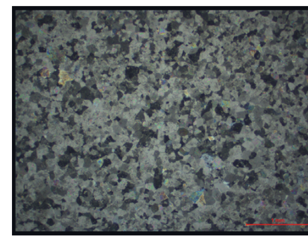
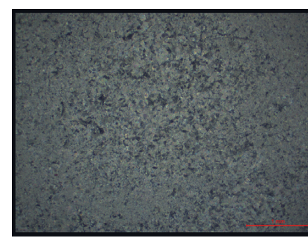
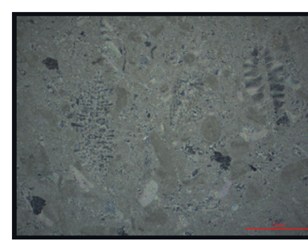
Table 2: Results of XRF semiquantitative analysis.

Content (%)	Marble unit			
	Adara	Emperador	Crema nera	Sand wave
CaO	55.16	47.06	55.09	55.03
MgO	0.67	14.7	1.13	0.53
Al_2O_3	0.38	—	0.16	0.3
MnO	0.035	0.022	0.02	—
CuO	0.026	0.032	0.026	—
Fe_2O_3	0.21	0.14	0.105	0.33
Cr_2O_3	0.058	0.04	0.025	0.036
SO_3	0.117	—	0.066	0.084
Lu_2O_3	0.02	0.055	0.04	0.04
V_2O_5	—	0.058	—	0.008
SrO	—	0.17	—	—
MoO_3	—	0.63	—	—
Yb_2O_3	—	0.01	—	—
La_2O_3	—	—	0.06	—
TiO_2	—	—	—	0.03
Eu_2O_3	—	—	—	0.06
Tu_2O_3	—	—	—	0.32
Loss on ignition	43.3	37.0	43.3	43.2

in surface roughness, and finer-grained abrasives (360, 600, and 800) cause a significant increase in surface glossiness values but the most pronounced effect is due to 5 Extra and Pulitore. It can also be seen from Figure 3 that there is an inverse relationship between final surface roughness and glossiness. Therefore, a distribution plot was drawn in order to show the relationship between roughness and glossiness values and calculate the correlation coefficient (Figure 4, $r = -0.96$) [1].

Analysis of the final roughness and glossiness values showed that glossiness of each marble unit was more than 87% except Emperador. Although the polishing tests were

Table 3: Mineralogical and petrographical characterizations of the marble samples.

Sample Name	Petrographic description	Thin section
Adara	Yellowish gray-colored, massive, and fine-grained "micritic limestone." The main component is micritic carbonate minerals; however, large carbonate crystals (calcite) are also present. In some sections, calcite minerals are observed to be dense and in contact with each other. Binding between minerals is not observed. Numerous thin veins intersecting each other give a segmented appearance to the marble and can be observed in macroscopic scale. Veins are filled with carbonate crystals (calcite)	
Emperador	Pale yellowish brown, massive, and fine-grained "calcitic dolomite." It consists of crystalline carbonate minerals (dolomite and a small amount of calcite). Marble gains rotational movement because of its position between nonparallel strike-slip faults. It shows a tectonite structure with both small and large particles, and these particles are bound to each other with calcite cement. Heterogeneously distributed, irregular, carbonate-filled veined structure is observed throughout the grains	
Crema nera	A very pale orange-colored, massive, and fine-crystallized "micritic limestone." It consists of micritic carbonate minerals. Slightly larger grains of carbonate (calcite) were observed to be bound by the cryptocrystalline mud binding	
Sand wave	Yellowish gray, massive, and fine-grained "biomicritic limestone." The main component is micritic carbonate minerals. The interiors of these small grains are filled with micritic carbonate minerals. Also, fine-grained carbonate oolite and fossil shells were observed in some places. There is ferrous water in its structural stilolit gaps, and this hematite-stained water causes redness in these parts	

conducted under the same operational conditions, the glossiness of Emperador turned out to be 80% which is lower than the other samples. In order to clarify the reason behind this difference, parameters affecting the surface glossiness were investigated. In a previous study conducted by Erdoğan [3], it was stated that geologic discontinuities such as cleavage, porosity, crystal boundary, fillings of the microfractures, and also the types of mineral constituting the rock have a negative effect on the surface glossiness [3]. In terms of physical properties, the Emperador unit was found to be more porous (Table 1) than the other marble units. The micro- and macropores in the structure of the Emperador absorb incoming beams and diminish the surface glossiness values. By taking mineralogical and petrographical characterizations into account, we can say that discontinuities such as filled fractures and the intersecting veins reflect the incoming beams in different directions. When analyzed in terms of the chemical content, the higher rate of MgO and the lower rate of CaO in the structure of the Emperador (Table 2) compared to the other marble units are significant. It was stated in previous studies that the increase in MgO ratio in the marble structure has a negative effect on surface roughness and glossiness [8, 12], which supports our findings.

To examine the effects of each physicomechanical property on surface roughness and glossiness values, correlation and regression analyses were conducted. A linear correlation ($r \geq 0.95$) was observed between porosity and the surface quality. With increasing porosity, roughness also increased while glossiness decreased (Figures 5(a) and 5(b)). There is an inverse relationship between UCS and roughness as well as ITS and roughness (Figures 5(c) and 5(e)), whereas the relationship between UCS (or ITS) and glossiness is directly proportional (Figures 5(d) and 5(f)). The correlation coefficients between the UW, BAR, FS, and SH test results and polishing test results were lower than 48%, and thus, these values were not high enough to suggest the existence of a relationship between them.

4. Conclusion

In this study, polishing tests were applied on four types of limestones under fixed operational conditions. Glossiness and roughness values were measured after each polishing

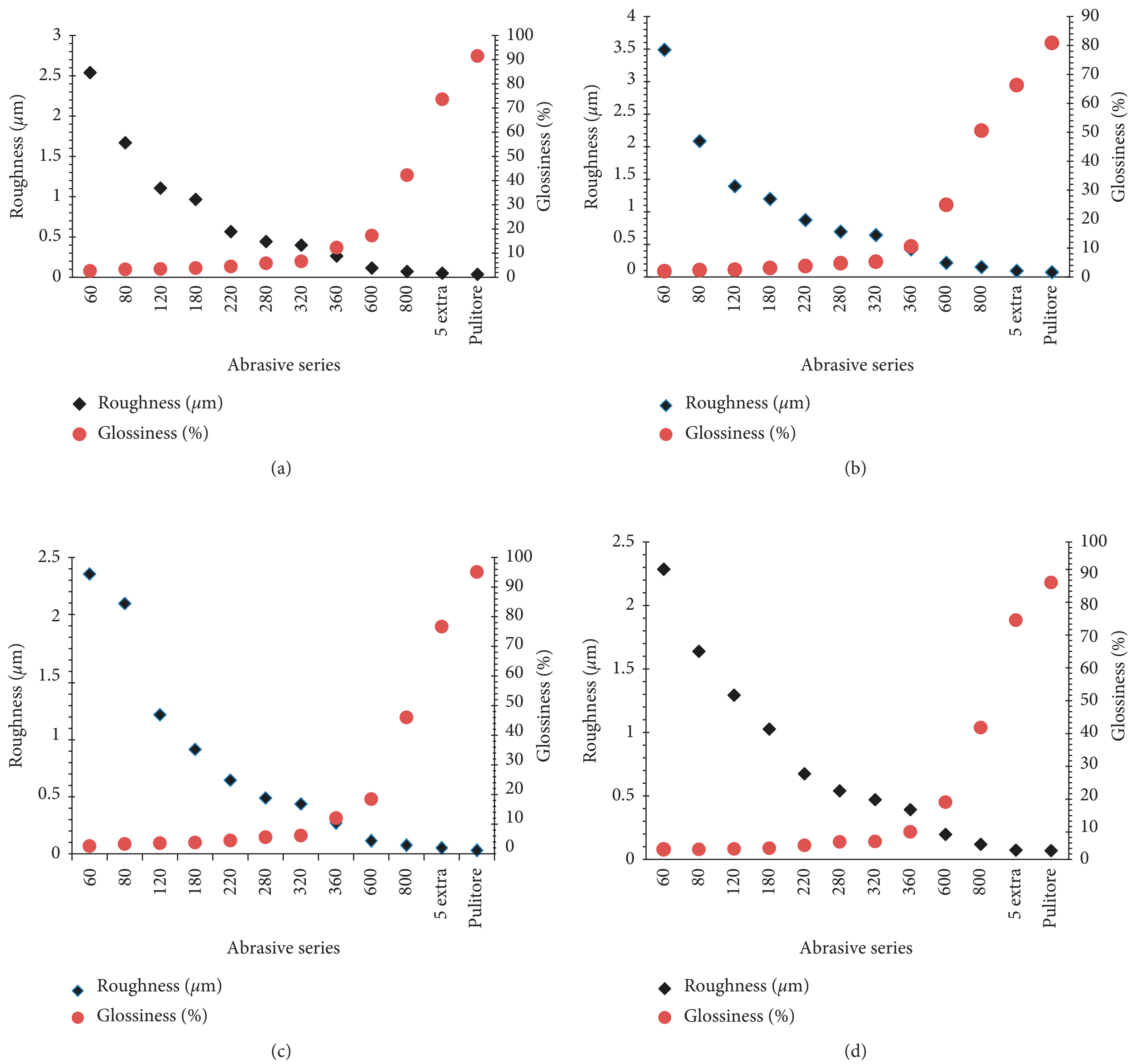


FIGURE 3: Surface roughness and glossiness values versus abrasive number for (a) Adara, (b) Emperador, (c) Crema nera, and (d) Sand wave.

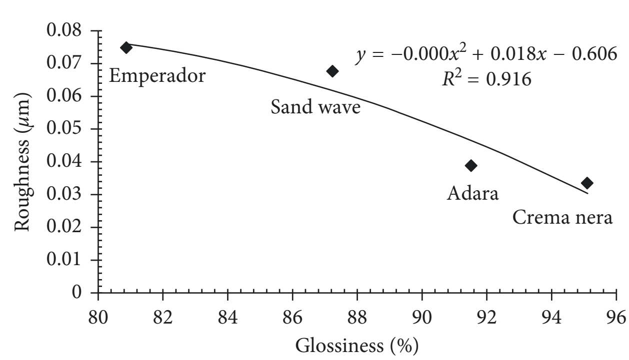


FIGURE 4: Roughness versus glossiness.

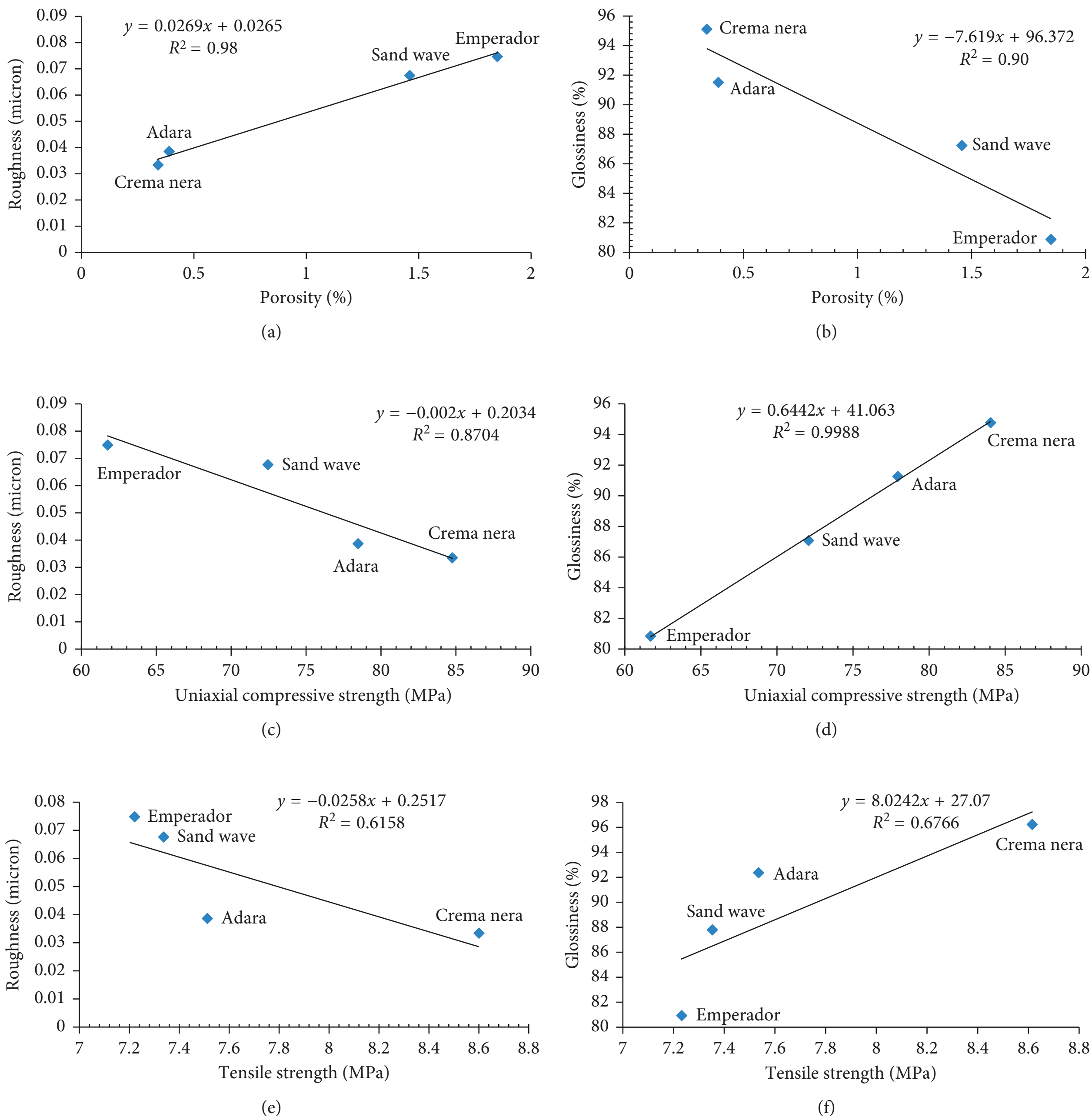


FIGURE 5: Physicomechanical properties versus roughness and glossiness. (a) Porosity versus roughness. (b) Porosity versus glossiness. (c) Uniaxial compressive strenght versus roughness. (d) Uniaxial compressive strenght versus glossiness. (e) Tensile strenght versus roughness. (f) Tensile strenght versus glossiness.

stage for all specimens. Considering the polishing test results, it is clear that 60, 80, and 120 numbered abrasives with coarse grains have a more prominent effect on the decrease of the surface roughness levels while glossiness values did not show a remarkable increase up to 320 numbered abrasive, and also finer-grained abrasives have the dominant effect on the increase of the glossiness values. It was seen that there is a good correlation ($r = 0.96$) between final surface glossiness and roughness values, and glossiness increases with decreasing roughness.

Although all the marble samples were of limestone and the polishing tests were applied under the same operating conditions, final surface glossiness of the Emperador unit was lower than the other units. The reason for that is the fact that the micro- and macropores in the structure of Emperador absorb the beams rather than reflecting them, and discontinuities such as filled fractures and intersecting veins reflect the incoming beams in different directions. Also, a high amount of MgO in marble samples has a negative effect on the surface quality. Based on laboratory measurements, linear relationships were found between P, UCS, and ITS and the surface quality.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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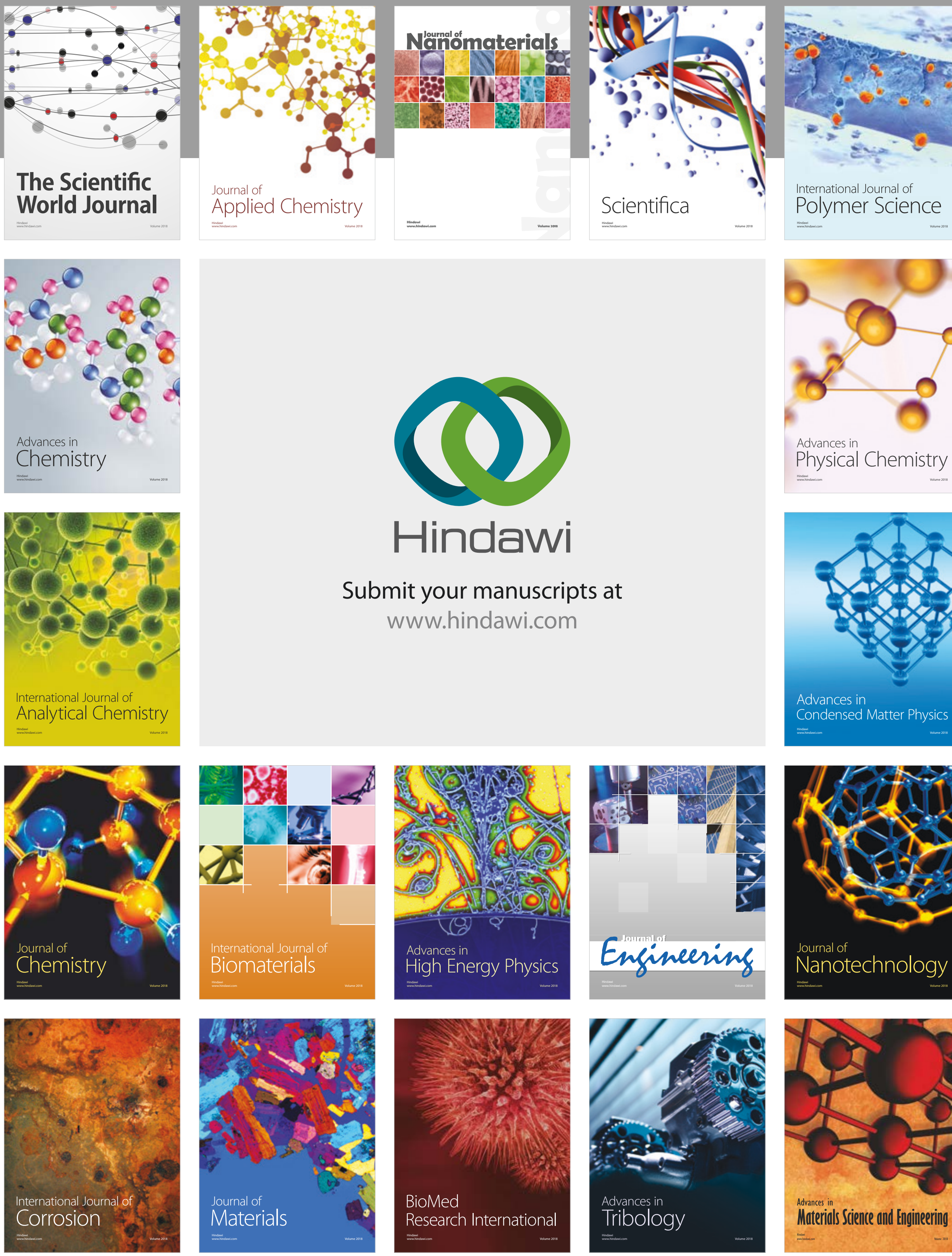

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