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Nanowax Application that Increases Stain Resistance as Well as Brightness in Ceramic and Porcelain Tiles

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Abstract

Polishing ceramic tiles enhances both aesthetics and durability by smoothing surfaces, improving light reflection, and facilitating cleaning. This process involves mechanical abrasion and chemical treatments, where surfaces are sanded and polished using specialized machines and compounds. The porosity structure of ceramics is critical for polishing quality, as it affects stain resistance and gloss. This study investigates the efficacy of Nanowax, a colloidal silica-based coating, in improving stain resistance and brightness by tailoring particle sizes to surface porosity. Results show that smaller particle sizes enhance gloss and stain resistance, particularly for ceramics with small pores, as evaluated per ISO 10545-14 standards.

Keywords: Nanowax; ceramic polishing; glossy tiles; porosity structure; colloidal silica.

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1. Introduction

Although polished porcelain and ceramic tiles are preferred due to their high gloss and aesthetic appearance, they face staining problems due to micro-scale porosity on the surface. According to the ISO 13006 standard, porcelain tiles with a water absorption rate below 0.5% generally have low porosity due to their dense sintered structure; however, approximately 5-8% residual porosity may remain within this structure [1]. During the polishing process (lapatura), a layer usually 0.5-1.0 mm thick is removed from the surface and in this process, previously closed pores are opened to the surface, forming open pores [2]. Although the diameter of these pores is usually <5 µm, pores with diameters of 10-20 µm or larger may occasionally appear [3]. These micropores on the surface allow external agents to penetrate beneath the surface, which can lead to staining. The staining tendency observed on polished surfaces is directly related to the distribution, size and number of these pores [4].

One of the commonly used tests for assessing stain adhesion on ceramic surfaces is ISO 10545-14, which evaluates stain cleanability on a five-level scale, with the highest class (Class 5) describing surfaces where the stain can only be completely removed with hot water [5]. Polished porcelain tiles may have difficulty reaching this class due to the exposure of pores. Therefore, the surface treatment agents applied to the surface after polishing are of critical importance both to increase the gloss and to provide stain resistance [6]. Initially, organic wax or resin-based coatings were used for this purpose; however, it was observed that such coatings caused problems such as yellowing, peeling and scratching over time [7]. Colloidal silica-based systems, which have been developed in recent years to overcome these shortcomings, stand out in post-polishing surface protection thanks to both chemical and mechanical additives [8].

Products containing colloidal silica contain nano-sized (usually 10-50 nm) amorphous SiO_2 particles and these particles penetrate into the pores on the surface and condense in the pore with the evaporation of water, forming a glass-like filling [9]. Thus, both the surface becomes smoother and the staining tendency decreases. However, these fixed size particles, which are widely used in the literature, do not give ideal results for every tile type [10]. If the particle size is too large relative to the pore diameter, the particles cannot penetrate into the pores, leaving a void below the surface. Conversely, if the particles are too small, they may be insufficient to fill large pores or cracking may occur after drying [11]. In these cases, stain resistance cannot be achieved at the desired level.

The main hypothesis of this study is that tailoring the polishing agent particle size to the porosity structure of the tile surface will yield more effective results in terms of both gloss and stain resistance. In this context, the effects of organosilane binders and surfactants in the applied formulations on particle stability and effective size were also evaluated [12]. Organosilanes are binders that both provide adhesion of silica particles to the surface and form crystal-like network structures after drying [13]. Surfactants, on the other hand, ensure that the dispersion remains stable and spreads evenly on the surface; however, they may also cause particle coalescence [14]. Therefore, in this study, the effects of the chemical additives used on this process were investigated as well as the adaptation of the particle size according to the surface porosity.

In this article, the interactions of polishing agents with surface porosity, approaches to particle size selection, the role of organosilane binders and surfactants are discussed in detail in the light of the literature and patents published in the last 10 years, and the potential of porosity sensitive polishing formulations is presented.

2. Literature Review

Although porcelain and ceramic tile surfaces have very low water absorption after sintering, the amount of open porosity increases after polishing [1]. Romero and his colleagues (2015) identify 4 main types of porosity in porcelain tiles: open pores (<5 µm), small closed pores (~5-10 µm), large closed pores (>10 µm) and intergranular voids [3]. During polishing, some of these closed pores open to the surface, forming stain-prone areas [4]. Therefore, the total porosity of the polished tile surface consists of both newly exposed voids and existing microcracks [2]. Hutchings and his colleagues (2005) reported that porcelain tile surfaces polished with very fine abrasives (e.g. 1000 mesh) have invisible but light scattering pores that limit the gloss [4].

In staining tests with ISO 10545-14, it has been previously reported that pore diameters on the surface, especially in the range of 15-60 µm, are a critical microstructural parameter that increases stain retention [6][5]. Such pores are both large enough to accommodate pigment and to draw in liquid by capillary effect [6]. It is stated in the literature that pores in this diameter range should be effectively sealed to maximize stain resistance [5]

Wax-based products initially used in post-polishing surface treatments offered short-term solutions but were limited in terms of optical clarity and durability [7]. Formulations containing colloidal silica, on the other hand, infiltrate into the pores after being applied to the surface, condense in these areas and form a glass-like filling, thus increasing both gloss and stain resistance [8]. However, fixed size (~20 nm) colloidal silicas are not suitable for all types of surface porosity [10]. As the size of the pores increases, the filling effect of these particles weakens and cracks may occur after drying [11].

In some academic and patent-based studies in the literature, it has been reported that one-dimensional particle systems may be insufficient for pore closure [15]. Therefore, it is suggested that 'dual-mode' sol-gel based coatings using different sized silica particles together can fill both micro and macro sized pores more effectively. It has also been reported that such systems provide high stain resistance in the ISO 10545-14 test [15].It has also been emphasized that organosilane binders form a chemical bond between the silica particles and the surface, while surfactants increase wettability and ensure the homogeneity of the coating [13][14]

As a result, there are few examples of porosity-specific particle size adjustment in the literature, which increases the originality of the presented work. The study aims to develop a new generation polishing approach that provides high gloss and stain resistance by evaluating the effectiveness of binders and surfactants in the formulation as well as particle size - pore diameter matching.

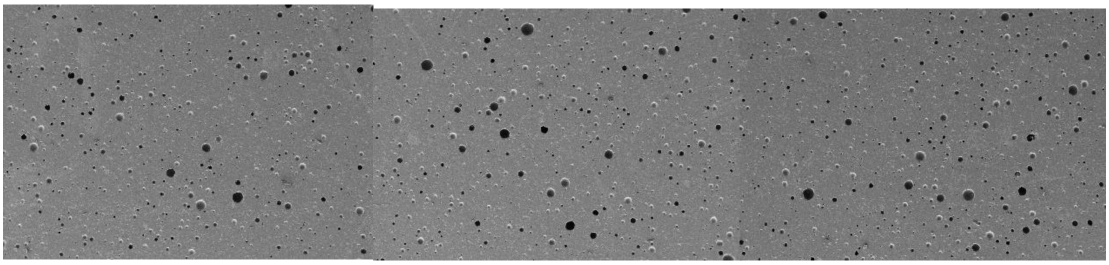
3. Method

In this study, some experimental methods were used to characterize the porosity structure of ceramic materials. Porosity distribution and pore morphology of the samples, gloss measurements and stain tests according to ISO

10545-14 standard were performed.

The porosity distribution and pore morphology of the samples were examined using scanning electron microscopy (SEM). The samples were coated with gold-palladium coating and made conductive before analysis. SEM images were taken at 50x magnification and the size of the pores were measured. The size of the pores varied between 20-80 µm.

Nanowax coated and uncoated samples containing different sizes of colloidal silica were compared on a Zeiss Sem device.



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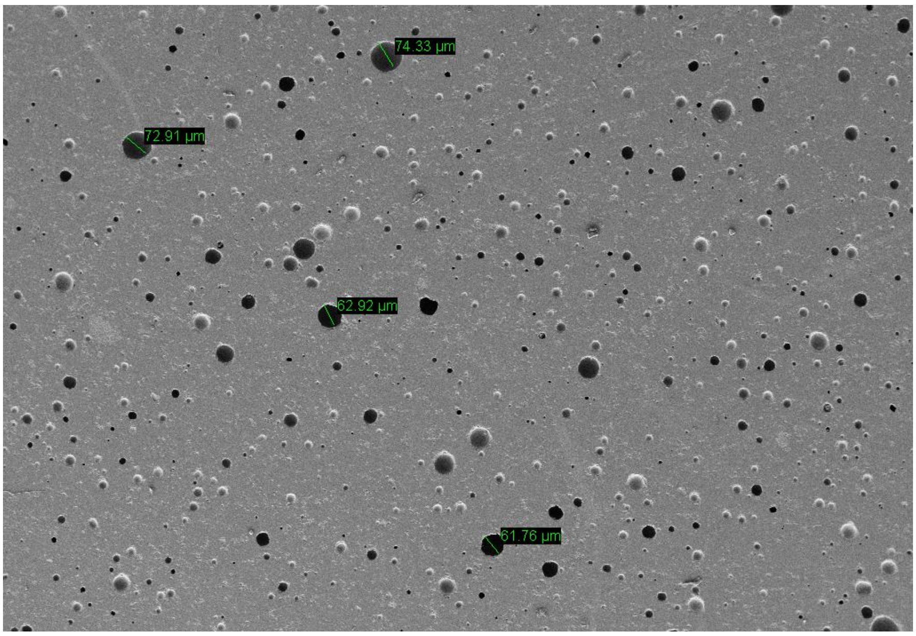


(d)

Figure 1: 50x SEM images of ceramics without polishing coating and dimensions of pores

The similarities and differences between the Nanowax solutions used in coated ceramics are given in **Table 1.**

Table 1: Comparison of nanowax solutions

	Nanowax 1	**Nanowax 2**	**Nanowax 3**
Colloidal silica %	40	40	40
Organosilan	Teos	Teos	Teos
Surfactant	Triton X-100	Triton X-100	Triton X-100
Lubricant	Polyethylene glycol	Polyethylene glycol	Polyethylene Glycol
Colloidal silica pH	9	9,5	10,5
Colloidal silica size	9 nm	15 nm	30 nm

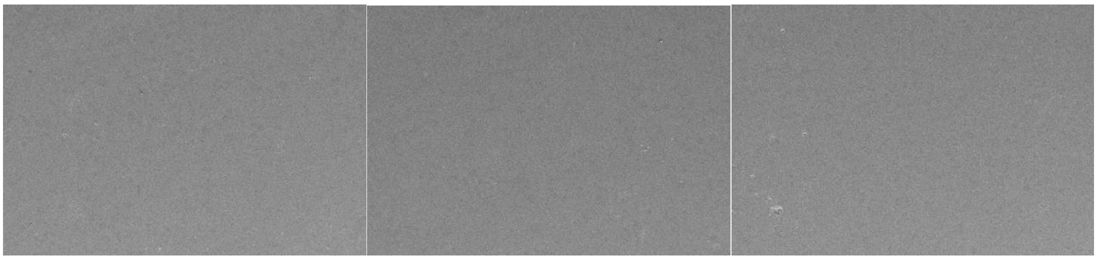
The importance of the selection of colloidal silica as a priority in nanowax production is emphasized. The size of the colloidal silica affects the size of the nanowax. Colloidal silicas for nanowax production were selected from the levacil series of Nouryon company. For all three samples, 3 different sizes of colloidal silica were selected from the levasil series. Tetraethylorthosilicate chemical of Dow company was used as a binder for each sample. A surfactant was also added to clean the nanowax on the ceramics. This surfactant is again Triton-X-100 from Dow. Polyethylene glycol was used as polishing agent in each sample. Here, formulations with 3 different sizes were obtained.

Table 2: Particle size comparisons of nanowaxes

	Nanowax 1	Nanowax 2	Nanowax 3
Nanowax particle size	20nm	35nm	55nm

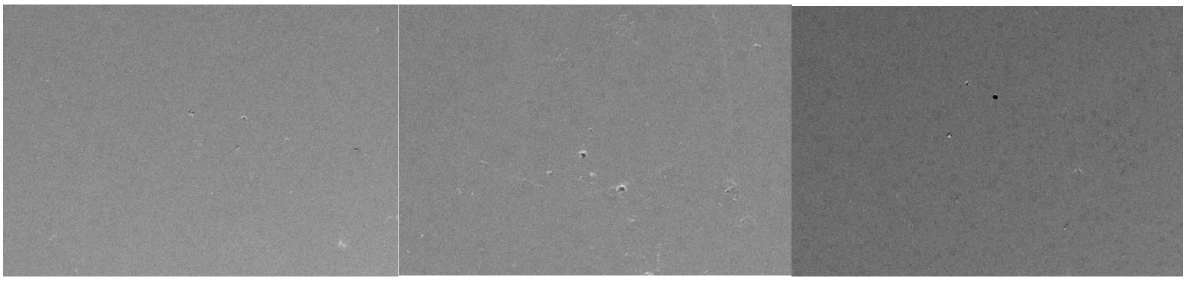
After the size measurement of the nanowaxes, the ceramics were polished by polishing method with 40-50 g per m^2. Gloss measurements of ceramics were made with TM- 8830 3 angle glossmeter. Comparisons are given in Table 3.

Images of the pores of the coated ceramics were taken with the Sem device. The rate at which the pores were closed after Nanowax application was observed.



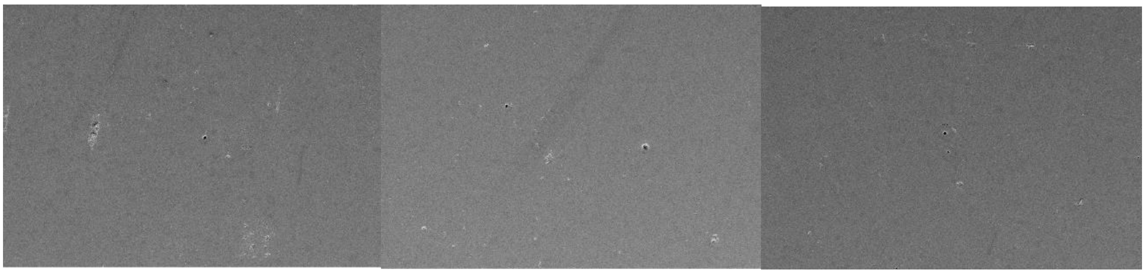
(a) (b) (c)

Figure 2: of pores after polishing using 9nm size colloidal silica



(a) (b) (c)

Figure 3: of pores after polishing using 15 nm colloidal silica



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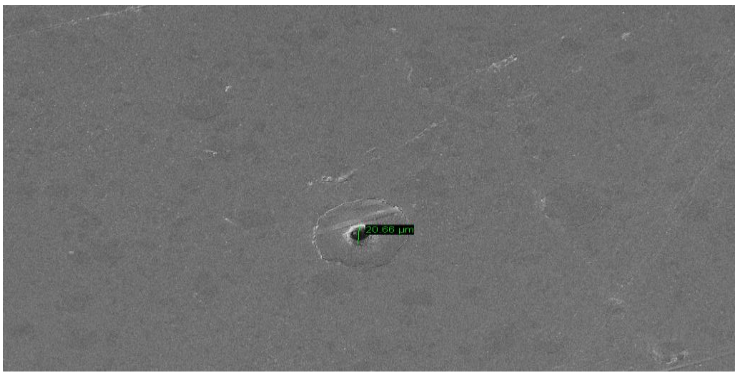

(d)

Figure 4: Image of pores after polishing using 30 nm colloidal silica and the size of the pore magnified 200x (d)

Finally, staining tests were performed according to ISO 10545-14 standard.

Each contaminant was left on each tile for 24 hours. At the end of 24 hours, the stain resistance of the ceramics is checked according to the treatment sequence. For Treatment A, the ceramics are washed under running hot water (50-55$^{(0}$)C) for 5 minutes. Then the surface of the ceramic is wiped with a damp cloth.

Process B, the ceramics are cleaned with a weak cleaning agent (cleaning agent with a pH of 6.5-7.5) with a non-abrasive sponge. The surface is then rinsed with running water.

Process C, the ceramics are mechanically cleaned with a strong cleaning agent (cleaning agent with a pH of 9-10). For example, it can be cleaned with a brush with a diameter of 8 cm, hard bristles and a rotational speed of approx. 500 rpm.

Process D, the ceramics are immersed in a suitable solvent and left for 24 hours. The surface is thoroughly rinsed under running water and then wiped with a damp cloth. Cleaning is considered complete if any of the solvents remove the stain. These solvents are usually a 3% concentration of Hydrochloric acid solution, 200g/l potassium hydroxide solution or acetone.

Cleaning operations and scoring are done according to Figure 5.

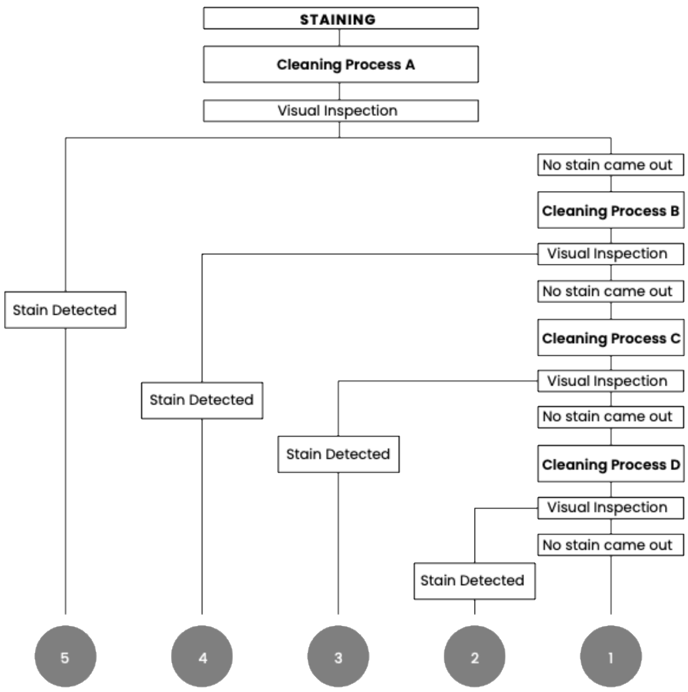

Figure 5: Schematic of cleanability of ceramic stains

4. Results and Disccusion

The gloss of the ceramics at 60 degrees was taken into account. Glosses from different points on the ceramic were compared.

Table 3: Gloss comparisons of ceramics

	Nanowax 1 coated Ceramic	*Nanowax 2-coated Ceramic*	*Nanowax 3-coated Ceramic*
Brightness measurements	100 101 105 103 103 108 107 105 105 106	103 102 100 99 104 103 101 101 102 105	99 101 99 100 98 101 102 100 99 98

Table 4: Scoring of ceramics against stainers according to ISO 10545-14 standard

	Nanowax 1	Nanowax 2	Nanowax 3
Black Soluble Coffee with Sugar	5	4	4
Coffee with milk and sugar	5	5	4
Black Tea with Sugar	5	5	4
Kola	5	4	4
Ketchup	5	4	5
Mayonnaise	5	5	5
Fruit Juice (cherry)	5	4	4
Blue Ink	5	4	4
Colored Marker Pen	5	5	5
Gray Joint Sealant	5	5	4
Alkaline Cleaning Agent	5	5	5
Acidic cleaning agent	5	5	4
Iodine	5	4	3

The superior performance of Nanowax 1 aligns with Romero and his colleagues findings that micro-pores (<5 μm) are critical for stain retention [3]. Smaller particles penetrate and seal these pores, preventing capillary action [6]. Compared to traditional wax-based coatings, which suffer from yellowing and peeling [7], Nanowax 1's organosilane binders enhance adhesion and durability, forming a crystalline network [13]. Unlike fixed-size colloidal silica systems (~20 nm) that crack in larger pores [11], Nanowax's tailored particle sizes address diverse porosity profiles. For instance, Nanowax 3's larger particles (55 nm) were less effective for the tested ceramics' small pores, leading to incomplete sealing and lower stain resistance (e.g., iodine, Class 3). This supports the hypothesis that particle size-pore diameter matching is critical.

Compared to dual-mode silica dispersions in US20200123456A1 [15], Nanowax's combination of organosilanes and surfactants ensures homogeneous coating and improved wettability [14], offering a practical advantage for industrial applications. However, the study focused on ceramics with 20-80 µm pores; larger or smaller pore distributions may yield different results, warranting further investigation.

5. Limitations

This study has several limitations. First, the experimental work was conducted on a single type of ceramic tile with relatively small pore sizes. The performance of Nanowax formulations on larger-pored or differently structured ceramics (e.g., red-bodied tiles, porous wall tiles) remains to be evaluated. Second, environmental factors such as humidity, temperature during application, and long-term exposure to cleaning agents were not assessed. These conditions may influence the stability of the silica-based coating over time. Lastly, the scope did not include the economic or lifecycle cost comparison of silica-based versus traditional organic wax systems, which could be useful for industrial decision-making.The findings of this study confirm that smaller colloidal silica particle sizes enhance both the gloss and stain resistance of ceramic tiles with fine surface porosity. These results are consistent with the studies of Alves and his colleagues (2006) and Akarsu & Kara (2014), which emphasized that effective pore sealing is critical for stain prevention. However, unlike previous research that utilized monodisperse silica sols, this study demonstrates that even small variations in particle size (e.g., 9 nm vs. 15 nm) can significantly affect the performance of the polishing layer, especially on surfaces with pore diameters ranging between 20–80 µm.Furthermore, the experimental comparison between Nanowax 1, 2, and 3 formulations reinforces the hypothesis that particle-pore matching is essential. While previous approaches focused on average pore blocking, this study provides SEM-based evidence that particle aggregation, surface wetting behavior, and binder interactions (such as TEOS crosslinking) all influence gloss retention and stain removal performance.These insights support the development of adaptive formulations based on ceramic surface morphology, which can be particularly valuable for manufacturers seeking to optimize polishing treatments for various tile categories.

6. Conclusion

Within the scope of this study, the differences in the porosity structures of ceramics were investigated. According to these porosity differences, the effect of Nanowax particle size on the gloss and stain resistance of ceramics was shown. Open pores negatively affect the cleaning performance of the products. The cleanability of polished surfaces varies depending on the amount of open pores on the product surface. In the study, it was observed that ceramics polished with Nanowax with small particle size showed activity against all contaminants, which ensures that the ceramics will be contaminated later and will have a longer life.

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