Mühendis ve Makina / Engineer and Machinery 66, 719, 293-312, 2025

Mühendis ve Makina / Engineer and Machinery
https://dergipark.org.tr/tr/pub/muhendismakina

INCREASING THE ABRASION RESISTANCE OF FLOOR TILES BY USING NATURAL BONE POWDERS

Yavuz ERGÜN[1*]

[1] Department of Chemistry Engineering, Faculty of Engineering and Natural Sciences, Usak University, Usak
ORCID No : http://orcid.org/0000-0001-5883-2078

Keywords

Ceramic, glaze, natural bone, wear resistance, abrasion

Abstract

Ceramic tiles are subjected to constant compression and abrasion. Since ceramic materials are brittle, the surfaces of porcelain tiles are subject to continuous abrasion and deterioration of surface properties. In order to reduce this deterioration observed on the porcelain tile surface, a study was conducted to increase the abrasion resistance of floor tile glazes using natural animal bones. Natural animal bones were ground in the range of 38-45 microns and added to the floor tile glaze recipe at a rate of 1-8% by weight and applied to floor tile glazes. While the reinforced bone powders do not cause a significant increase in the viscosity of the glaze, they cause a more matte appearance. These samples were sintered at 1070 °C, prepared in 2X2cm^2 sizes and their mechanical wear properties were investigated.

Abrasion tests were carried out on a ball disc abrasion tester in a dry environment without oil and at room temperature. Abrasion tests were carried out at a sliding speed of 0.3 m/s, under a load of 5 N and 50-100 meters in length. The abrasion resistance increased by about 20% compared to the specimens without bone dust. As a result of the abrasion test, microstructure properties were analyzed by scanning electron microscopy (SEM) and X-ray energy dispersive spectroscopy (EDS). Surface distortion values and wear volume ratios of bone powder additives were measured with Taylor-Hobson Rugosimeter Surtronic 25 device. As a result of the destructive tests, It was found that the resistance to abrasion of porcelain floor tile glazes increased with the increase in bone dust content.

* yavuz.ergun@usak.edu.tr
doi : 10.46399/muhendismakina.1726355

DOĞAL KEMİK TOZLARI KULLANILARAK YER KAROLARININ AŞINMA DİRENCİNİN ARTIRILMASI

Anahtar Kelimeler

Seramik, sır, doğal kemik, aşınma direnci, abrazyon

Öz

Seramik karoları sürekli basma ve aşınmaya maruz kalmaktadır. Seramik malzemeler gevrek bir özellik gösterdiğinden dolayı porselen karoların üstleri devamlı aşınmaya ve yüzey özelliklerinin bozulmasına neden olmaktadır. Porselen karo yüzeyinde gözlenen bu bozulmayı azaltmak amacıyla doğal hayvan kemikleri kullanılarak yer karosu sırlarının aşınma dirençlerinin arttırmaya yönelik bir çalışma yapılmıştır. Doğal hayvan kemiklerinin 38-45 mikron aralığında öğütülüp yer karosu sır reçetesine ağırlıkça %1-8 oranında ilave edilerek yer karosu sırlarına uygulanmıştır. Takviye edilen kemik tozları, sırın viskozitesinde önemli bir artışa neden olmazken daha mat bir görünüme neden olmaktadır. Bu numuneler 1070 ^{o}C'de sinterlenerek,, 2X2cm^{2} boyutlarında hazırlanıp mekanik aşınma özellikleri incelenmiştir.

Aşınma testleri bilya disk aşınma test cihazında, yağsız kuru ortamda ve oda sıcaklığında gerçekleştirilmiştir. Aşınma testleri 0.3 m/s kayma hızında, 5 N yük altında ve 50-100 metre uzunluğunda aşınması yapılarak gerçekleştirilmiştir. Aşınma dayanımları, kemik tozu içermeyen numunelere göre yaklaşık % 20 artmıştır. Aşınma test sonucunda aşınma yerlerinden alınan numunelerden taramalı elektron mikroskobu (SEM) ile mikro yapı özellikleri ve X-ışınları enerji dağılımlı spektroskopi (EDS) analizleri yapılmıştır. Kemik tozu katkıların yüzey bozulma değerleri, aşınma hacmi oranları Taylor-Hobson Rugosimeter Surtronic 25 cihazı ile ölçülmüştür. Aşınma testleri sonucunda % kemik tozu oranlarının artmasıyla porselen yer karosu sırların aşınmaya karşı dirençlerinin arttığı tespit edilmiştir.

Araştırma Makalesi
Başvuru Tarihi : 25.07.2024
Kabul Tarihi : 07.02.2025

Research Article
Submission Date : 25.07.2024
Accepted Date : 07.02.2025

1. Introduction

Porcelain tiles are usually composed of clay, feldspar and quartz raw materials. The mechanical properties of porcelain tiles depend not only on the chemical, mineralogical and impurity properties of the raw materials. It also depends on the technological parameters used in the production process. These parameters, grain size, size range, raw material ratios used in the tile recipe, firing temperature, firing time, press pressure and tile thickness also have an effect on strength and wear behavior (El-Raghy, Blau, and Barsoum, 2000; Elmas and Tarhan, 2019; Yangzi, Sijia, Hao Hongyue, Han, and Wei, 2024).

It has focused on the glaze properties of the tiles to ensure that glazed porcelain tiles, especially those to be used in densely populated public areas, have a longer service life (Cheng, Ke W, Wang, Shui, and Liu, 2012; Fortanet, Gabaldon, Bakali, Nunez, Perio, and Carda, 2006). If the tiles used in these areas have low abrasion resistance, it causes their color, shine and patterns to lose their properties in a short time. It has shown that more specialized ceramic surfaces are needed to eliminate such undesirable situations. Meeting such needs can be done by enabling the development of glass-ceramic systems (Firas, Eshamsul and Muralithran, 2018; Rasteiro, Gassman and Santos 2006).

Depending on the application, traditional glazes are sintered at temperatures of 950 to 1430 °C and in most cases oxidizing firing conditions are used, whereas a reducing environment is needed for certain products. Glazes are used in many fields of application. electrical porcelain, refractories, tiles - wall and floor tiles, tableware - crockery, crockery, mugs, ceramic mugs and dinner plates, ornaments - Figurines and souvenirs, Sanitary ware - Bath tubs, toilets and sinks (Alzahrani 2022; Yekta, Alizadeh, and Rezazadeh 2006).

These glazes, which are used in many different areas, are used for different purposes. These include antibacterial, antimicrobial and antifungal capability, self-cleaning and photocatalytic activity, mechanical strength and chemical resistance and imparting different properties.

The reactive metal oxide nanoparticles used in the glaze recipe have been shown to exhibit a lethal effect against bacteria. The preparation, characterization, surface modification and functionality of these nano-sized inorganic particles have opened up the possibility of a new generation of bactericidal materials (Stoimenov, Klinger, Marchin and Klabunde 2002). Ag-doped P2O5-SiO2 monoliths prepared by sol-gel method and porous glaze structure were found to have good antibacterial properties (Liu, Chen, Song, Ye, Lu, and Li, 2008).Enamel glazes prepared by adding ZnO and MnO2/CuO nanocrystals into the glaze and their homogeneous distribution have shown to have excellent antibacterial properties

(Hanxue, Wenqian, Yiting, Yang, Yuanjing and Guodong 2023). Materials used in antimicrobial ceramic products, floor and wall tiles, silver ions and phosphate, TiO_2 are used in glazes. Silver ions and different metal ions are used in sanitary ceramic glazes (Esteban, Malpartida, Esteban, Pecharromán and Moya 2009; Oku and Shigeru, 2009; Reinosa, Enríquez, Fuertes, Liu , Men´endez and Fernandez, 2022). Metal oxides such as ZnO, CuO, MnO_2,Fe_2O_3 and MgO are used as antibacterials (Cho, Kim, Ghim, Hong, Kim.Y, and S. Cho, 2020). Using ZnO/Cu-ZnO-rich glaze on porcelain tiles has enabled the creation of multifunctional ceramic surfaces, including super hydrophilicity, self-cleaning, antibacterial properties and photocatalytic activity (Acikbas, Calış. Acikbas, Dizge and Belibagli, 2024)

In the studies on the mechanical properties of glazes, it was stated that the increase of Anorthite used in the glaze recipe increased the refractive index and decreased the transparency, but increased the Vickers hardness and flexural strength (Zhenhong, Silu, Lifeng, Yanqiao, Zhenyu and Xiaorong, 2024). For the long-term stability of zirconia hardened alumina (ZTA), the wear rate decreased with the addition of Mn in aqueous media (Li, Zhao, Q. Li, Gong, Zhang, Xu, Liang and Leng, 2024) Refractory high entropy alloys (RHEAs) show great potential as structural components for aerospace. However, the lack of wear resistance and the increased coefficient of friction at room temperature limit its use. In the study to overcome this, the wear rate of composite ceramics made with the addition of NbMoWTa(h-BN)x, a powder mixture of Nb, Mo, W and Ta, reached as low as 1.32×10^{-8} mm^3/Nm.(Pei, Du, Han. Wang, Hu, Li, Zhou and Hai.Wang, 2024). In glaze studies containing bone, Ca and P ions (hydroxyapatite) increased the compatibility of the expansion coefficient at the interface between the glaze and the composition (Kara, and Stevens, 2002). It was emphasized that the mechanical properties of tile surfaces were improved by applying frit composed of CaO-ZrO_2-SiO_2 (CZS) to tile surfaces by plasma spray and sintering at low temperature (Bolellia, Cannilloa, Lusvarghia, Manfredinia, Siligardia, Bartulib, Loretob and Valenteb, 2005).

Ceramic materials show a brittle property. This is due to their ionic and covelent bonding. Since they do not have a metallic bonding property due to free electrons as in metals, their ability to change shape is almost non-existent. This is why ceramic structures can be worn by machining. Cracks form on the surface and under the surface of ceramic materials. These cracks then connect to form small cracks in ceramic materials (crack network). This causes ceramic materials to break and deform (Glease, 1995).

Moisture absorption of ceramic materials is known to accelerate fracture. In their studies on chemical absorption embrittlement, Michalske and Bunker found that hydrogen atoms in water molecules, O ions, and hydroxyl radicals adsorb onto metallic ions. As a result, hydroxyl surfaces are formed, strained bonds weaken and cracking accelerates (Fischer, 1990).

The wear properties of glazed floor tiles have been analyzed in different ways by researchers. Unfortunately, no research has been conducted on the friction and wear properties of floor tiles doped with natural bone dust. In the ceramic industry, it is important that such projects are easy to implement and cost-effective. The main objective of this research is to improve the friction and wear behavior of bone dust doped floor tiles. The microstructure and tribological parameters were investigated by optical microscopy, XRD, SEM, EDS, tests and ball disk tribotester.

2.Method & Experimental Data

2.1 Materials and sample preparation

Glaze raw materials and firite were obtained from Esan Eczacıbaşı Endüstriyel Hammaddeler San. ve Tic. A.Ş. Sodium Tripolyphosphate (STPP) and carbon methyl cellulose (CMC) were obtained from Foodchem, a supplier and manufacturer.The XRF compound values of the raw materials and frit included in the glaze recipe are given in Table 1. In the glaze recipe, natural bone powders were given as variables, whereas other compounds remained at a constant rate.

Table 1. Chemical Analysis Determined by XRF of Raw Material And Frit Used in Glaze (wt%)

Number	Components	Glaze Raw Material (%)	Frit Components (%)
1	Na_2O	1.0805	-
2	MgO	1.1282	1.8048
3	Al_2O_3	15.6289	6.8006
4	SiO_2	61.5474	66.6735
5	P_2O_5	0.1502	0.0436
6	SO_3	-	0.0557
7	K_2O	2.4645	3.6726
8	CaO	11.7683	15.3150
9	Cr_2O_3	-	0.0481
10	Fe_2O_3	0.3486	0.02955
11	ZnO	3.2474	5.2907
12	ZrO_2	1.330	-
13	**A.Z.**	**2.3060**	**-**

Single firing glaze application of industrial porcelain tiles was ground in a ball mill according to the glaze recipe given in Table 2. The prepared glaze was applied on 40x40 cm sized floor tiles by the airbrush method. In order to examine the tribological properties, it was sintered at 1070 °C and cut into 2x2 cm pieces and prepared for analysis. Figure 1 shows the process stages. Figure 2. Images of some samples subjected to abrasion tests after 50-100m are given.

CMC (carbon methyl cellulose) and STPP (sodium tripolyphosphate) were used to adjust the viscosity of the glaze before application to the tile surfaces. Viscosity values were measured according to the flow rate in a 100 cc Ford Cup with a bore diameter of 4 mm. When the amount of bone powder added according to the solid ratio in the glaze recipe was increased from 1% to 8% by weight, it was observed that the color of the tile surface became dull and the viscosity values increased. While the viscosity values were 20 seconds in the base samples (without bone dust additives), it increased to 24 seconds in the sample with 8% bone dust additives.

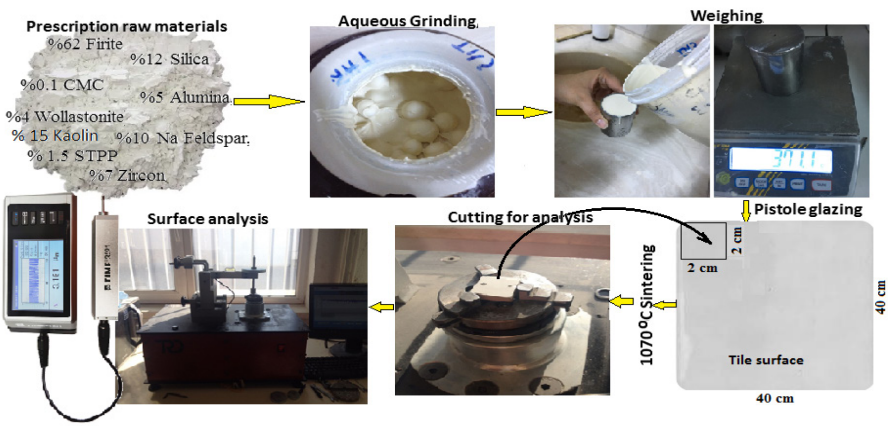

Figure 1. Application of Floor Tile Glazes And Preparation Stages For Analysis

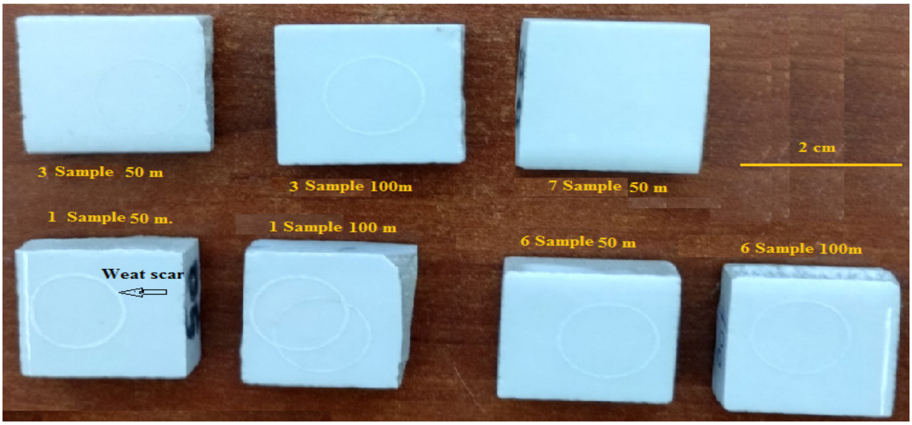

Figure 2 Post-Test İmages Of Abrasion Tested Samples

Table 2. Glaze Recipe and Usage Rates of Bone Powder in Glaze

% Raw materials	Without additive	Sample K1	Sample K2	Sample K3	Sample K4	Sample K5	Sample K6	Sample K7	Sample K8
Kaolinite	15	15	15	15	15	15	15	15	15
Natural bone powder	--	1	2	3	4	5	6	7	8
	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
CMC	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
STPP	50	50	50	50	50	50	50	50	50
Water									
GZT (Firit, Alümina,Feldispar,Zircon Silica,Wollastonite)	85	85	85	85	85	85	85	85	85

In this study, research and publication ethics were complied with.

2.2 Characterization and Measurement

SEM analysis of the weathered surfaces of the materials was obtained using a FEI Quanta 400 MK2 scanning electron microscope. EDS analysis was analyzed using EDAX Genesis XM 4i model detector. XRD analysis was performed with Rigaku

MiniFlex Desktop X-Ray Diffraction Device with standard scanning (2θ=2-70° range). Chemical analyses were performed on X-Ray Fluorescence Device (RIGAKU ZSX Primus) brand and model.

2.3 Friction and Abrasion

A ball-on-disk testing machine was used to perform the abrasion and friction tests of the natural animal bone powder doped tile specimens. Tungsten carbide-Cobalt balls with a radius of 4 mm provided by H.C. Starck Ceramics GmbH were used for wear tests. The abrasion tests were performed under dry friction operating conditions at room temperature, at sliding lengths of 50 and 100 m, at sliding speeds of 0.4 m/s, with a 5N load applied in a ball-on-disk arrangement. After the wear tests, the wear surfaces of the materials were calculated by multiplying the cross-sectional areas of the wear by the width of the wear trace obtained from the Taylor-Hobson Rugosimeter Surtronic 25 device. The abrasion rate was calculated by the below equality

$$Wk = \frac{Wv}{M.S}\ mm^3/Nm \tag{1}$$

Where Wk is the abrasion rate, Wv is the volume of wear, M is the applied load and S is the length over which the force is applied. Friction coefficients as a function of wear length were determined using TimeSurf Windows software, a friction coefficient program. The abraded surfaces were examined by SEM and EDS. The abrasive load is applied to the ball by means of a fixed cantilever arm which rotates by means of a motor. The same abrasion method has been studied on boronized material (Gunes, 2013). The schematic representation of the H.C. Starck Ceramics GmbH device used to perform wear tests is also given in Figure 3.

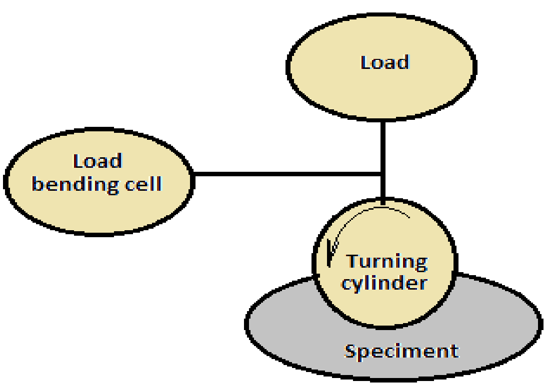

Figure 3. Schematic of the Slider On Cylinder Tribometer

3. Results and Discussion

3.1 Characterization of Materials

SEM and EDS images taken from the tile surfaces are given in Figure 4. Figure 4a-c shows SEM images taken from tile surfaces at different magnifications. Tile surfaces exhibit an amorphous structure due to molten glass and rapid cooling. Grain traces and borders do not show neck formation due to sintering. Figure 3d shows the elements of natural bone powders and the compounds that make up the glaze recipe in EDS analysis. In the quantitative analysis made on the tile surface, the element percentage amounts by weight are Oxygen 51.32, Silicon 23.34, Calcium 9.8, Aluminum 3.66, Zircon 7.72, Sodium 2.34, Potassium 1.74, Magnesium 0.35 and Phosphate 0.11, respectively.

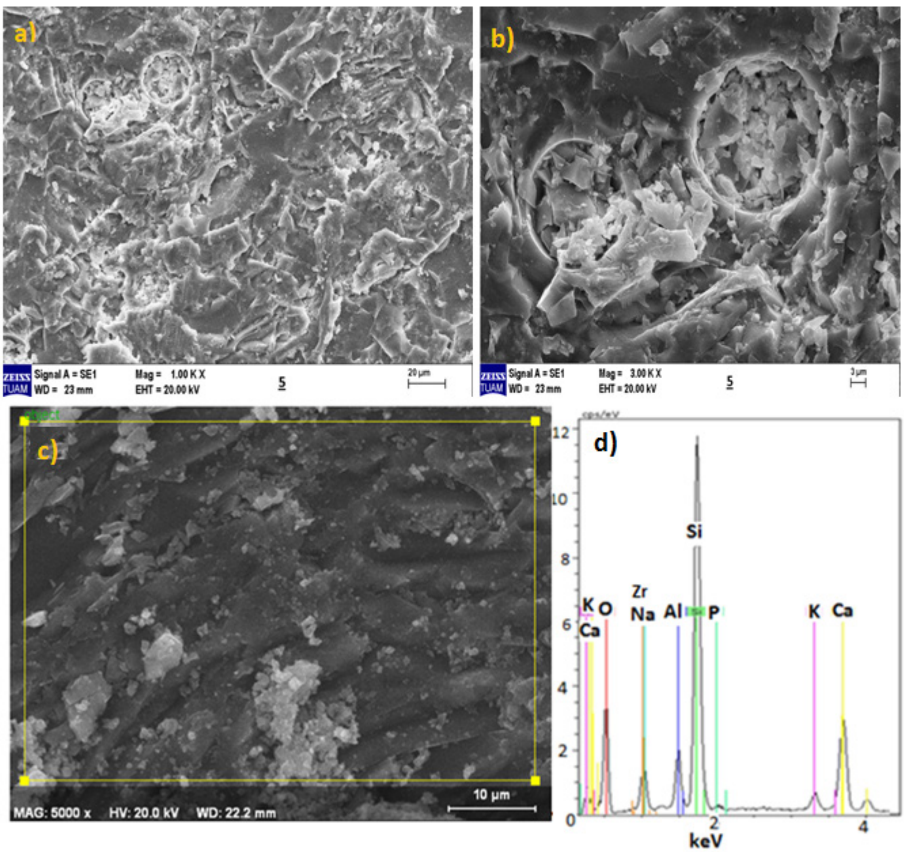

Figure 4. a-c SEM and d.EDS İmages From Tile Surfaces

SEM images of the wear tests performed on the specimens at a distance of 50 m are shown in Figure 5. Fig.5a shows the SEM image of the analysis taken from the sample without bone dust additive. Fig.4b,c and d show the SEM images of the specimens with 2, 6 and 8 g bone dust additives, respectively. SEM microstructure analysis shows that the amount of wear decreases with increasing bone ratio. It is observed that the glaze particles broken off as a result of abrasion are more scattered around due to more abrasion (abrasion scar) in the sample without additives. This is because the tile surface has a brittle structure as a result of its glassy properties. Therefore, ceramic structures can be worn by machining (Glease, 1995). Cracks occur on the surfaces and under the surfaces of ceramic materials. Continuous tensile stress occurs at the ends of these cracks. It can be said that the bone particles reinforced in the glaze recipe have the effect of reducing this tensile stress and have a barrier effect. Therefore, it is assumed that the wear rate decreases.

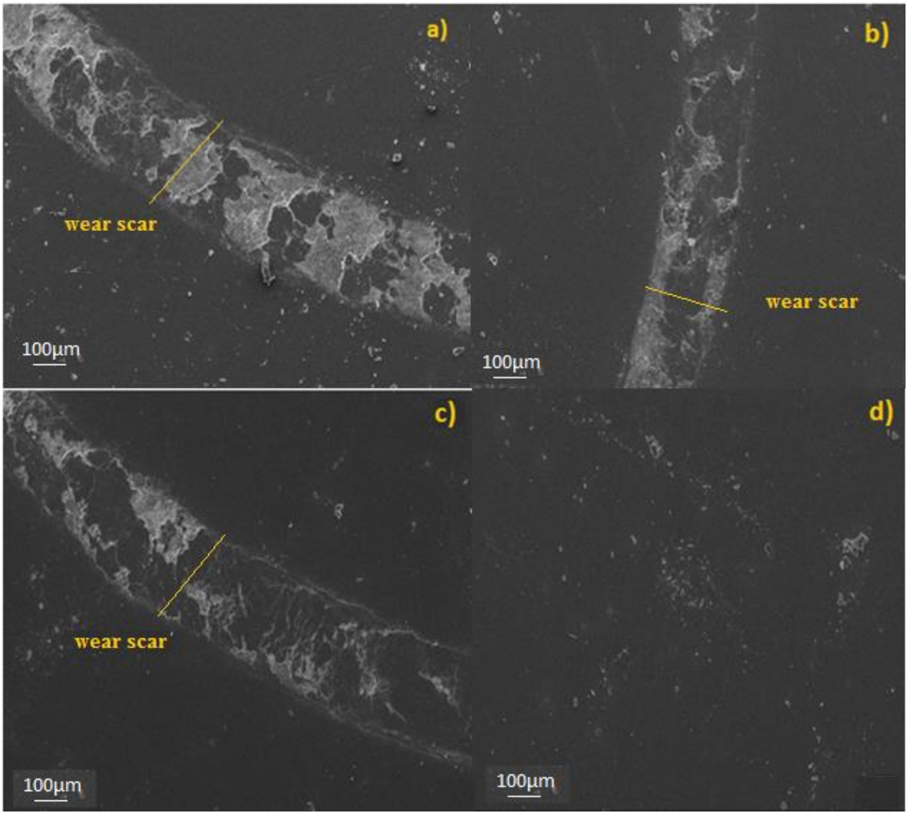

Figure 5. SEM Samples Abraded With Respect to 50 m are shown. a.) sample without bone dust additives, b.) with 2%, c.) with 6% and d.) with 8% bone dust additives by weight to the floor tile glaze recipe..

In Figure 6, it is seen that deeper and wider abrasions occur in samples after etching according to 100 meters in samples with bone powder additives, which are added to the floor tile glaze recipes at the same rate of 1-8%. As a result of abrasion, abrasive (scratching) and delamination (shedding of layers) abrasion has occurred. Figure 6a shows the wear marks, depth and flaking of the sample without bone dust additives. Figure 6 b, c and d samples contain 2.6% and 8% bone dust additives to the floor tile glaze recipe respectively. The amount of abrasion decreases significantly with increasing bone powder addition. It is seen that as the wear distance increases, the depth and amount of wear also increases.

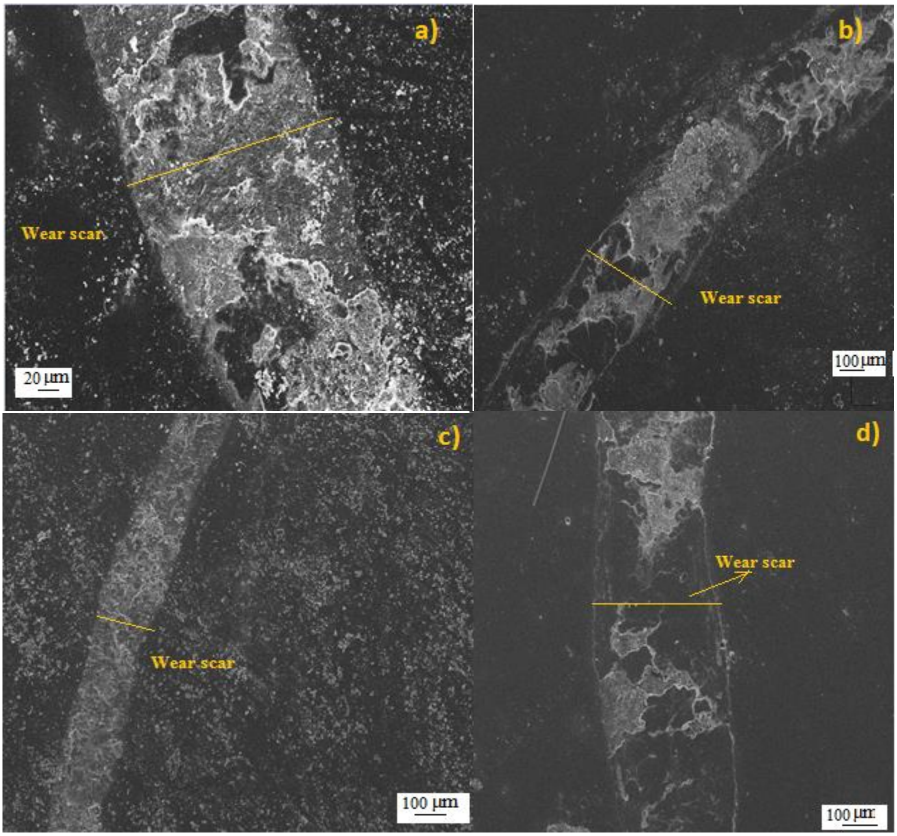

Figure 6. Shows the Microstructures of SEM Specimens Eroded by 100 m. It Contains a) bone powder additive free sample, b) 2% by weight to the floor tile glaze recipe, c.) 6% to the glaze recipe and d.) 8% bone powder additive

In this study, XRD analysis was made from the raw material mixtures that make up the glaze recipe. The results of the analysis are given in Figure 7. XRD analysis results showed the minerals of the raw materials entering the glaze structure. Albite mineral is an aluminum silicate with Na-Ca content. XRD analysis was not performed because the glaze layer on the floor tile shows molten glass amorphous properties.

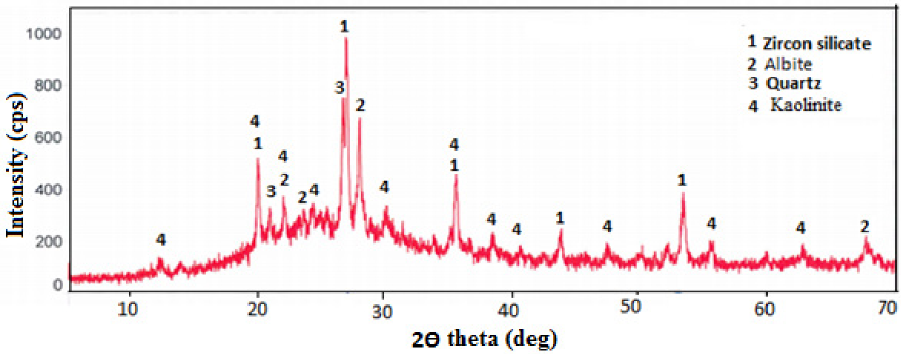

Figure 7. XRD Pattern of the Raw Materials That Make Up The Floor Tile Gaze Recipe

3.2 Determination of Modulus of Rupture (Flexural Strength) and Fracture Strength

In order to determine the modulus of rupture (flexural strength) and fracture strength of the floor tile materials, 5 of each sample were made and averaged. Analyses were performed at SAM (Ceramic Research Center) according to TS EN ISO 10545-4 Standard. The results of the analysis are shown in Table 3, which is given as a sample without bone powder additives. The formulas used to determine the modulus of rupture (flexural strength) and fracture strength are given in Equations 2 and 3. Table 4 shows the results of the loads and strengths averaged separately for the 8 samples without additives. It was determined that the flexural and fracture strengths increased by approximately 16% with the increase in the addition of bone powder additive. Although there is not much variability in tile hardness, while it was 3 according to Mohs hardness, it was 4 when the bone additive rate was 6-8%. According to TS EN ISO 10545-11 standard, ceramic tiles - glazed tiles - determination of cracking strength of glaze; determined as undamaged.

Table 3 Results of Modulus Of Rupture And Fracture Strength of the Specimen Without Bone Dust Additive

Number of experiments	Fracture load (N) (F)	Length between supports (mm) (L)	Width (mm) (b)	Thickness (mm) (h)	Modulus of rupture (Flexural strength) N/mm²	Breaking strength (N)
1	3886	583	610	10	54.62	3788
2	3687	583	610	10	52.85	3594
3	3975	583	610	10	56.98	3876
4	3796	583	610	10	54.42	3701
5	3898	583	610	10	55.88	3800
Average	3848	583	610	10	54.89	3751

$$Flexural\ strength = 3.F.L/2bh^2 \quad (2)$$

$$Breaking\ strength = FL/b \quad (3)$$

Table 4 Average Modulus of Rupture and Fracture Strengths of Bone Powder Reinforced and Unreinforced Specimens

% bone powder additives (number of samples)	Fracture load (N) Average (F)	Length between supports (mm) (L)	Width (mm) (b)	Thickness (mm) (h)	Modulus of rupture (Flexural strength) N/mm² Average	Breaking strength (N) Average
K0	3848	583	610	10	54.89	3751
K1	3963	583	610	10	56.81	3787
K2	4021	583	610	10	57.64	3843
K3	4040	583	610	10	57.91	3861
K4	4098	583	610	10	58.74	3916
K5	4155	583	610	10	59.56	3971
K6	4386	583	610	10	62.87	4191
K7	4425	583	610	10	63.43	4229
K8	4445	583	610	10	6372	4248

3.3 Friction and Wear Behavior

The roughness values of the sample surface were measured from 10 different places with the Rugosimeter roughness device. The surface roughness values of the samples = Ra: 0.2-0.22 µm were obtained. The friction coefficient values of the samples increased with the increase in the wear distance. As the amount of additive increased, friction coefficient values decreased. Bone dust additive has been found to cause a decrease in friction coefficient Figure 8 shows the friction coefficients obtained according to the wear distances. Table 5 shows the rates of reduction in friction coefficients with the addition of bone powder. The coefficient of friction of the sample without bone dust additive is taken as the base.

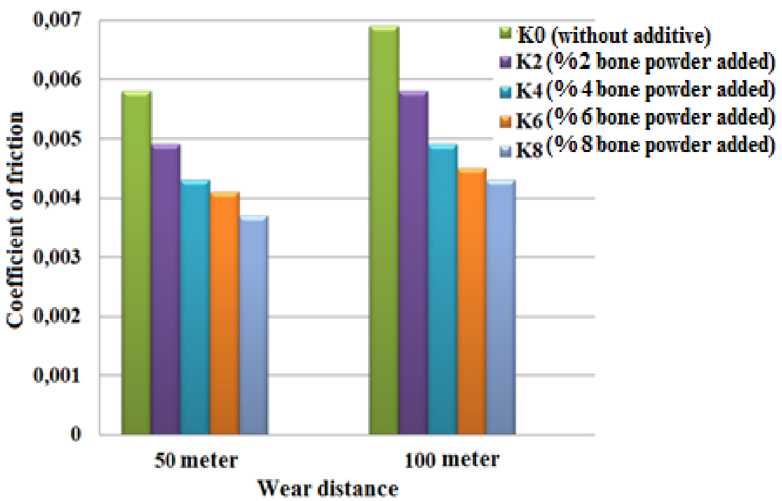

Figure 8. The Friction Coefficients of the Floor Tile Glaze Bone Powder With and Without Bone Powder

Table 5. Reduction Rates of Friction Coefficients at 50 and 100m

%Bone powder added rate (K experiment name)	Rate of reduction in friction coefficient at 50m	%Bone powder added rate (K experiment name)	Rate of reduction in friction coefficient at 100m
(without addition) 0.0058	-------	(without addition) 0.0069	-----
(K2) 0.0049	15.51	K2) 0.0058	15.84
(K4) 0.0042	27.58	(K4) 0.0049	28.98
(K6) 0.00401	30.86	(K6) 0.0044	36.23
(K8) 0.00365	37.06	(K8) 0.0042	39.13

As the wear distance (road; meter) increases, the wear rate increases. As the contribution amount increased, reductions occurred in the rate of wear. The addition of bone powder caused the friction coefficient to decrease and the wear rate to decrease. In Figure 9, the wear rates depending on the wear distance are given. Table 6 shows the reduction in wear rates with the addition of bone powder. The wear rate of the specimen without bone powder additive is taken as a base.

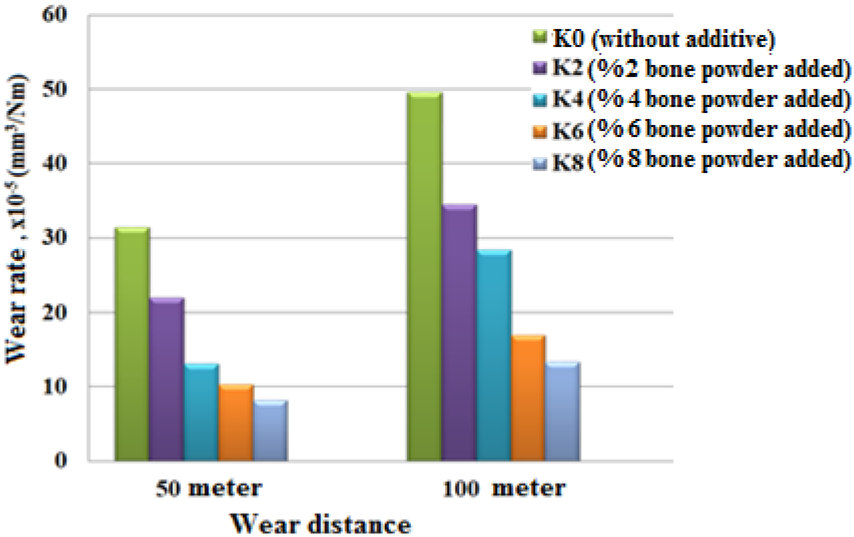

Figure 9. The Wear Rate (mm^3/Nm) of the Floor Tile Glaze Bone Powder With and Without

Table 6. Reduction Rates of Wear at 50 and 100 m

Wear rate at 50m 10^{-5}(mm^3/Nm)	Reduction in wear rate at 50m	Wear rate at 100m 10^{-5}(mm^3/Nm)	Reduction in wear rate at 100m
wear rate without additives (K0) 31	-----	wear rate without additives 49	----
K2) 22	29.03	35	28.57
(K4) 12	61.29	28	42.85
(K6) 10	67.74	16.5	66.32
(K8) 8	74.19	12	75.51

These tiles, which generally have porosity values below 0.3%, are ideal for floor coverings as they are resistant to all kinds of abrasion due to their hardness. Especially natural animal bones are very cheap and have gained importance in terms of easy application. Adding bone powders below 40μ to 1-8% by weight of the tile glaze recipe shows an improvement of up to 22% in abrasion rates. However, it was determined that the bone particles added at 8% caused dulling on the tile surfaces and at the same time there was a very slight increase in the amount of abrasion above this rate. Since the glaze layer applied on the refractory substrate (biscuit) has amorphous glass properties, the abrasion, scratching and pressing stresses applied to these surfaces cause a chip deformation on the glass surface. This is because ceramic materials are brittle due to their ionic and covelent bonding. Therefore, it can be said that ceramic structures increase their wear resistance with bone powders that can act as a barrier to abrasion and the crack network that may develop due to this.

4. Conclusions

In this study, wear behavior and some of the mechanical properties of glazes applied to natural bone-doped floor tile surfaces were investigated. Some of the conclusions can be drawn as follows.

- Surface roughness values of the specimens = Ra: 0.2 μm were obtained.
- The coefficient of friction values of the specimens increased with increasing wear travel distance.• As the amount of additive increased, friction coefficient values decreased.
- It has been determined that the bone powder additive causes a decrease in the friction coefficient.
- As the wear distance (road; meters) increased, the wear rate increased.
- As the % additive amount increased, the wear rate decreased.
- The addition of bone powder caused a decrease in the coefficient of friction and a decrease in abrasion rate..
- Bone powder additive increased the surface resistance of ceramic materials against abrasion.
- Abrasive (scratching) and delamination (shedding layers) wear has occurred as a result of wear.
- In ceramic structures, bone powders, which have a barrier effect against abrasion and the cracks and crack propagation that may develop accordingly, have increased their abrasion resistance.
- It has gained importance as it is an easy, effective, applicable, low-cost and result-oriented research that can be applied to floor tiles produced on an industrial basis.

- Figures 5 and 6 clearly show the difference in wear marks.
- Bone powder doped samples showed a 39% reduction in coefficient of friction and 75% reduction in wear rates.

Support: In our study, floor tiles and glaze preparation unit Umpaş Seramik Sanayi ve Ticaret A Ş. It was obtained from the enterprises.

Nomenclature

EDS	Scanning electron microscope
SEM	Scanning electron microscopy
EDAX	XM 4i model detector.
Wk	Abrasion rate
Wv	Volume of wear
M	Applied load
S	Length
CMC	Carboxymethyl Cellulose
STPP	Sodium Tripolyphostat
GZT	Flaks
XRF	X-Ray Fluorescence
XRD	X-Ray Diffraction
wt	Weight
Ra	Surface roughness value
keV	Kilo electron volt
K	Sample name
cps	Reflection intensity
F	Fracture load
L	Length between supports
b	Width
h	Thickness

References

Acikbas, G., Calis Acikbas, N., Dizge, N., Belibagli, P. (2024) Multi-functional ceramic glazes with nano ZnO/Cu–ZnO incorporation Ceramics International Volume 50, Issue 21, Part C, 1 November, Pages 43800-43810, https://doi.org/10.1016/j.ceramint.2024.08.233

Alzahrani,A.S. (2022) A Review of Glass and Crystallizations of Glass-Ceramics Advances in Materials Physics and Chemistry Vol.12 No.11, November 2022 DOI: 10.4236/ampc.2022.1211018

Bao, Z., Wang, S., Miao, L., Xu, Y., Cheng, Z., Wang, X. (2024) Preparation, properties and formation mechanism of transparent anorthite-based glass-ceramic glaze with high hardness Ceramics International Volume 50, Issue 14, 15 July, Pages 26182-26192 https://doi.org/10.1016/j.ceramint.2024.04.359

Bolellia, G., Cannilloa, V., Lusvarghia, L., Manfredinia, T., Siligardia, C., Bartulib, C., Loretob, A., Valenteb, T. (2005). Plasma-sprayed glass-ceramic coatings on ceramic tiles: microstructure, chemical resistance and mechanical propertiesJournal of the European Ceramic Society 25 1835–1853, https://doi.org/10.1016/j.jeurceramsoc.2004.06.018

Cheng, X,, S.Ke, Q., Wang, H.Wang., A.Shui., P. Liu. (2012) Characterization of transparent glaze for single - crystalline anorthite porcelain, Ceramics Internati-onal.38(6,) 4901- 4908 https://doi.org/10.1016/j.ceramint.2012.02.081

Cho, Y.S., Kim, H.K., Ghim, M.S., Hong, M.W., Kim, Y.Y., Cho, Y.S. (2020) Evaluation of the antibacterial activity and cell response for 3D-printed polycaprolactone/ nanohydroxyapatite scaffold with zinc oxide coating, Polymers 12 2193, https://doi.org/10.3390/polym12102193

Elmas, S., Tarhan, İ. (2019) The Effect of Combınatıon of Boric Acıd and Lithıum Carbonate on Sıntering And Mıcrostructure in Single Firing Wall Tile Journal of Scientific Perspectives Cilt: 3 Sayı: 2, 86 - 98, 30.04.2019 https://doi.org/10.26900/jsp.3.010

El-Raghy, T.P., Blau, M.W. (2000). Barsoum, Effect of grain size on friction and wear be-havior of Ti3SiC2, Wear 238 125–130,,http://dx.doi.org/10.1016/S0043-1648(99)00348-8.

Esteban Tejeda, L., Malpartida, F., Esteban Cubillo, A., Pecharromán, C., Moya, J.S. (2009) Antibacterial and antifungal activity of a soda-lime glass containing copper nanoparticles Nanotechnology, p. 20, 10.1088/0957-4484/20/50/505701, DOI 10.1088/0957-4484/20/50/505701

Fortanet, E., Gabaldon, S., Bakali, J., Nunez, I., Perio, M., & Carda, J.B. (2006) Developing of new glass-ceramic glazes that improve anti slip properties, Qualicer P.BC, 56-59.

Fischer, T.H. (1990). Friction and Wear of Ceramics” Scripta Metalurgica et Materialia, V.24, pp: 833838, https://doi.org/10.1016/0956-716X(90)90121-V

Firas, A.F., Sulaiman, E., Kutty, G.K. (2018). Ceramics Application of zirconia surface coating to improve fracture resistance and stress distribution of zirconia ceramic restorations Ceramics International 44; 21633–21640 , https://doi.org/10.1016/j.ceramint.2018.08.246

Glease, W.A. (1995). Friction and Wear of Ceramics", ASM Handbook, V. 18, pp: 812815,

Gunes, İ. (2013). Wear Behaviour of Plasma Paste Boronized of AISI 8620 Steel with Borax and B2O3 Paste Mixtures, Journal of Material Scientific Technol, 29, 662, https://doi.org/10.1016/j.jmst.2013.04.005

Hanxue, X., Wenqian, C., Yiting, C., Yang, H., Yuanjing, C., Guodong, Q. (2023) Preparation and characterization of enamel glaze containing metal oxide nanocrystals for antibacterial application, Journal of Non–Crystalline Solids Volume 619, 1 November 2023,122561 https://doi.org/10.1016/j.jnoncrysol.2023.122561

Kara, A., Stevens, R. (2002). Interactions between an ABS type leadless glaze and a biscuit fired bone china body during glost firing. Part I: preparation of experimental phases, J. Eur. Ceram. Soc. 22 (7) 1095–1102. DOI:10.1016/S0955-2219(01)00419-8

Li,Y.X., Zhao, P.X., Li, Q., Gong, Y.L., Zhang, C.B., Xu, Q., Liang, W.L., Leng, Y.X. (2024) Revealing the wear mechanisms of Mn-doped zirconia-toughened alumina ceramics in physiological solutions, Ceramics International, https://doi.org/10.1016/j.ceramint..11.308.

Liu, H., Chen, Q., Song, L., Ye, R., Lu, J., and Li, H. (2008).Ag–Doped Antibacterial Porous Materials with Slow Release of Silver Ions, Journal of Non–Crystalline Solids, 354 (12–13), 1314–1317, https://doi.org/10.1016/j.jnoncrysol.2007.02.098

Oku, T., Shigeru, T. (2009) Antibacterial Mildewproof Glaze Composition for Ceramic Products, Patent US7250178B2. 2015.Nanotechnology 20, https://doi.org/10.1088/0957-4484/ 20/50/505701.

Pei, X., Du, Y., Wang, H., Hu, M., Li, Y., Zhou, W., Wang, H. (2024) Attaining exceptional wear resistance in an in-situ ceramic phase reinforced NbMoWTa refractory high entropy alloy composite by Spark plasma sintering Wear Volumes 558–559, 15 December, 205572 https://doi.org/10.1016/j.wear.2024.205572

Rasteiro, M.G., Gassman, T., Santos, R., & Auntes, E. (2006) Crystalline phase characterization of glass - ceramic glazes, Ceramic International (33) 345 -354 https://doi.org/10.1016/j.ceramint.2005.10.002

Reinosa, J.J., Enríquez, E., Fuertes, V., Liu, S., Men´endez, J., Fernandez, J.F. (2022) The challenge of antimicrobial glazed ceramic surfaces Ceramics International Volume 48, Issue 6, 15 March Pages 7393-7404,https://doi.org/10.1016/j.ceramint.2021.12.121

Stoimenov, P. K., Klinger, R. L., Marchin, G. L., and Klabunde, K. J. (2002) Metal Oxide Nanoparticles as Bactericidal Agents, ACS Publications Langmuir, 18 (17),6679–6686. http://dx.doi.org/10.1021/la0202374

Yangzi, L,, Sijia, S., Hao D., Zhang, H., Zhang, Ha., Li, W. (2024) Preparation of TiO2–SiO2–CaCO3 composite opacifier by hydrophobic agglomeration and mechanism of inhibiting glaze yellowing Ceramics International volume 50, ıssue 13, part b,1 july pages 24195 - 24204, https://doi.org/10.1016/j.ceramint.2024.04.151

Yekta, B. E., Alizadeh, P., & Rezazadeh L. (2006) Floor tile glass- ceramic glaze for improvement of glaze surface properties, Journal of European Ceramic Society (5918), 1-2. https://doi.org/10.1016/J.JEURCERAMSOC.2005.12.016