



# The Effect of Talc, Zirconium Oxide and Titanium Oxide Additions on the Physical Properties of Feldspathic Porcelain

## Talk, Zirkonyum Oksit ve Titanyum Oksit Katkılarının Feldspatik Porselenin Fiziksel Özellikleri Üzerindeki Etkisi

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### Abstract

**Aim:** The primary goal of this research is to evaluate how the physical characteristics of feldspathic porcelain are influenced and its mechanical durability reinforced through the incorporation of talc, titanium oxide, and zirconium oxide—materials frequently utilized in the ceramics sector—at various concentrations.

**Material and Method:** Talc, zirconium dioxide, and titanium dioxide were added to the base feldspathic porcelain powder at concentrations of 2 wt% and 5 wt%. The investigation aimed to assess color stability, flexural strength, hardness, and crack propagation. Subsequent microstructural analysis was conducted using SEM. Statistical analysis was performed using one-way analysis of variance (ANOVA), Tukey HSD, and Tamhane T2 tests ( $p<0.05$ ).

**Results:** Mechanical testing revealed that while all experimental groups demonstrated increased flexural strength relative to the control, this elevation was statistically significant only for the 2% zirconium dioxide group ( $p<0.05$ ). With respect to hardness, every experimental group containing additives yielded significantly superior results compared to the control samples ( $p<0.05$ ). Conversely, concerning crack propagation, a decrease (improvement) relative to the control was observed exclusively in the 5% talc group, whereas all other variations resulted in greater crack lengths.

**Conclusion:** The obtained results revealed that all reinforcement materials used improved the hardness and flexural strength of feldspathic porcelain. Particularly, talc-reinforced groups presented more advantageous data compared to other groups in terms of color stability and crack propagation. Statistical analyses confirm that there are significant differences.

**Keywords:** Dental porcelain, talc, titanium dioxide, zirconium, materials testing

### Öz

**Amaç:** Bu çalışmada, seramik endüstrisinde kullanılan zirkonyum oksit, talk ve titanyum oksidin değişik oranlarda eklenmesiyle, feldspatik porselenin fiziksel özelliklerinde meydana gelen değişimlerin incelenmesi ve malzemenin mekanik dayanımının geliştirilmesi hedeflenmektedir.

**Gereç ve Yöntem:** Araştırma kapsamında, baz materyal olarak seçilen feldspatik porselen tozuna, ağırlıkça %2 ve %5 oranlarında talk, zirkonyum dioksit ve titanyum dioksit takviyeleri yapılarak; numunelerin renk stabilitesi, esneme direnci, sertlik ve çatlak ilerleme davranışları incelenmiştir. Mekanik testlerin ardından seçilen numunelerin mikroyapısal incelemeleri ile gerçekleştirilmiştir. İstatistiksel analiz Tek Yönlü Varyans Analizi, Tukey HSD ve Tamhane T2 testleri ile yapılmıştır ( $p<0,05$ ).

**Bulgular:** Mekanik dayanım testlerinde, tüm deney gruplarının esneme direnci kontrol grubuna kıyasla yükseliş göstermiş olup, özellikle %2 zirkonyum dioksit katkılı grubun sergilediği artışın istatistiksel anlamlılık düzeyine ulaştığı belirlenmiştir ( $p<0,05$ ). Sertlik verileri incelendiğinde ise, istisnasız tüm katkılı grupların kontrol grubundan daha yüksek değerde olduğu ve bu farkın istatistiksel anlamlılık düzeyine ulaştığı belirlenmiştir ( $p<0,05$ ). Çatlak ilerlemesi hususu incelendiğinde, kontrol grubuna nazaran yalnızca %5 talk içeren örneklerde bir düşüş kaydedilmiş; buna karşın geri kalan grupların tamamında çatlak uzunluklarının arttığı belirlenmiştir.

**Sonuç:** Elde edilen sonuçlar, kullanılan tüm takviye materyallerinin feldspatik porselenin sertlik ve esneme dayanımını geliştirdiğini ortaya koymuştur. Özellikle talk katkılı gruplar, renk stabilitesi ve çatlak ilerlemesi açısından diğer gruplara kıyasla daha avantajlı veriler sunmuştur. İstatistiksel analizler anlamlı farklar olduğunu doğrulamaktadır.

**Anahtar Kelimeler:** Diş porseleni, talk, titanyum dioksit, zirkonyum, malzeme testi



## INTRODUCTION

Restoring missing teeth and dental tissues with materials that are biologically compatible, aesthetic, and resistant to chewing forces has long been a quest in dentistry. Although amalgams, composites, and restorative cements have been used successfully in recent years, they are not suitable for extensive restorations. Today, porcelains have gained a significant place in restorative dentistry. They provide excellent aesthetic results similar to natural teeth.

Despite the high thermal resistance of porcelain materials, they remain inherently brittle, resulting in restricted strength and fracture toughness. Consequently, sudden fluctuations in occlusal force or temperature may precipitate structural failure.<sup>[1]</sup> The utility of these materials, especially in load-bearing molar regions, is restricted by inherent drawbacks including low ductility, a fragile nature, and insufficient resistance to both fracture and impact forces.<sup>[2,3]</sup> Thus, it is imperative to augment the mechanical attributes of porcelain to maximize its longevity and success in clinical applications. BV

One effective strategy for enhancing the mechanical attributes of feldspathic porcelain involves the incorporation of reinforcing materials.<sup>[4]</sup> The introduction of nanoparticles modifies the porcelain's physical characteristics, influencing mechanical parameters such as durability, elasticity, and density, thereby elevating the material's overall performance.<sup>[3]</sup> To this end, researchers have investigated various additives at differing concentrations to optimize these properties, including silver oxide (AgO), alumina (Al<sub>2</sub>O<sub>3</sub>), zirconia (ZrO<sub>2</sub>), titanium dioxide (TiO<sub>2</sub>), hydroxyapatite (HA), and platinum (Pt).<sup>[5-9]</sup>

This investigation focuses on determining how the physical attributes of feldspathic porcelain are altered by the incorporation of titanium oxide, zirconium oxide, and talc at various dosages, specifically aiming to bolster the material's mechanical durability.

## MATERIAL AND METHOD

The experimental stage was performed at Tokat Gaziosmanpaşa University's Department of Prosthodontics and Department of Physics. Sample manufacturing was completed at Bizim Dental Laboratory. Financial backing for this research was granted by the Scientific Research Projects Coordination Unit at Gaziosmanpaşa University.

Ethical Statement: Ethics committee approval was waived due to the purely in vitro nature of this investigation.

To evaluate parameters such as flexural strength, hardness, crack dimensions, and color stability, this study modified feldspathic porcelain using varying concentrations of talc, titanium dioxide, and zirconium dioxide. The base matrix consisted of commercial Ceramco 3 feldspathic dentin powder (Dentsply Degudent GmbH, USA), whereas the additives were procured from Kalaçlar (Ankara, Turkey).

The study design consisted of seven distinct groups, each containing eight specimens (n=8). A group consisting of pure dentin porcelain powder without any additives was established as the control.

Talc, titanium dioxide and zirconium dioxide compounds were weighed on a precision balance to be 2% and 5% by weight of Ceramco 3 commercial dentin porcelain powder and mixed with a mechanical mixer. Specified ratios of dentin porcelain powder and additives were suspended in an ethanol medium. The mixture was subjected to ultrasonic homogenization for 30 minutes prior to a 1-hour mechanical blending phase. Following solvent evaporation, the specimens were dried in a vacuum chamber for 24 hours.

Metal molds were produced (thickness 1.2±0.2 mm; diameter 12 mm).<sup>[10]</sup> Disk-shaped samples were prepared using these metal molds. Specimen preparation adhered strictly to the manufacturer's guidelines for the porcelain powder. Sintering was then performed using a specific program in a vacuum porcelain furnace (Programat P300, Ivoclar Vivadent, Schaan, Liechtenstein). The temperature was 650°C for the first 4 minutes, reaching 910°C in 4 minutes with a temperature increase of 50-70°C per minute, and the firing process was completed by holding at this temperature for 2 minutes.

To achieve optimal surface smoothness, the specimens were first treated with a 15–20 µm grit diamond bur. Subsequently, a rubber polishing instrument was applied to complete the finishing protocol. To ensure the elimination of residual particles, every specimen underwent a 10-minute ultrasonic cleaning cycle in distilled water before the testing phase commenced.

**Color Change Test:** A VITA Easyshade spectrophotometer (Vita Zahnfabrik, Bad Säckingen, Germany) was utilized to assess the color characteristics of the porcelain samples, with the instrument being calibrated before every individual reading. Measurements for each specimen were repeated three times based on the CIEDE2000 color system, and the average value was recorded.

**Biaxial Flexural Strength:** Using the piston-on-three-ball method, biaxial flexural strength was evaluated in accordance with ISO 6872. The setup involved a bending test device (Shimadzu AGS-X, Japan) fitted with a 1.4 mm diameter loading tip. To distribute the load evenly and reduce stress concentration, a thin plastic film was positioned between the indenter and the ceramic sample. Force was exerted centrally on the specimens using a crosshead velocity of 1 mm/min, persisting until structural failure was observed.

**Hardness Test:** For the purpose of stabilization and ease of manipulation during Vickers hardness testing, the samples were encased within acrylic resin blocks. Surface preparation involved polishing for 30 seconds at 300 rpm using a velvet cloth and a water-cooled 0.3 µm Al<sub>2</sub>O<sub>3</sub> suspension. Vickers hardness scores were calculated by applying a 10 N force onto the polished specimen surfaces for a duration of 10 seconds via a High Wood HWDM-3 testing unit (Japan).

**Metallurgical Microscope Analysis:** After the hardness tests, suitable crack models were examined using a metallurgical microscope (Shimadzu DUH-W201S, Japan). Images of the samples observed under the metallurgical microscope were recorded. Crack lengths were determined from these recorded images.

**SEM and EDS Analysis:** Microstructural analysis was performed using a TESCAN Mira III scanning electron microscope (Brno, Czech Republic) housed at the Sivas Cumhuriyet University Advanced Technology Research and Application Center. Before microscopic examination, a gold-palladium (Au-Pd) coating was applied to the chosen porcelain samples to facilitate conductivity. Furthermore, an Energy Dispersive X-ray Spectroscopy (EDS) unit attached to the SEM was utilized for elemental analysis.

**Statistical Analysis**

Data analysis was conducted using the SPSS v17.0 package designed for Windows. Descriptive statistics are reported as arithmetic means alongside standard deviations (SD). Differences among the experimental cohorts were determined via One-way ANOVA. For detailed pairwise analysis, Tukey HSD and Tamhane’s T2 methods were applied, accepting significance at  $p < 0.05$ .

**RESULTS**

**Table 1** presents the analysis of  $\Delta E_{00}$  values derived from color stability testing. Upon statistical review, marked disparities were identified across the mean values of every experimental group ( $p < 0.001$ ). Specifically, the groups containing titanium dioxide exhibited the highest  $\Delta E_{00}$  values, whereas the talc-added groups demonstrated the lowest, indicating minimal color shift.

**Table 1: Comparison of groups by  $\Delta E_{00}$  values**

	$\Delta E_{00}$	Post Hoc Differences
	Mean±Std. Deviation	
ZrO <sub>2</sub> (2%)	17.16±1.87	Statistically significant variations were detected among all experimental groups ( $p < 0.05$ )
ZrO <sub>2</sub> (5%)	29.70±2.68	
TiO <sub>2</sub> (2%)	46.62±8.75	
TiO <sub>2</sub> (5%)	60.95±3.77	
Talc (2%)	2.50±0.70	
Talc (5%)	9.83±1.07	
p	<0.001*	

p: Values obtained from One-way ANOVA analysis, \*Indicates a statistically significant difference at the  $p < 0.05$  level, Multiple comparisons were conducted via Tamhane’s T2

The findings obtained from the biaxial flexural strength assessments are presented in **Table 2**. Quantitative analysis demonstrated that the mean values across the groups varied significantly ( $p = 0.001$ ). Specifically, the group containing 2% zirconium dioxide demonstrated significantly higher flexural strength compared to both the 2% talc ( $p = 0.038$ ) and control ( $p = 0.039$ ) groups.

**Table 2: Comparison of groups by biaxial flexural strength**

	Biaxial Flexural Strength (MPa)	Post Hoc Differences
	Mean±Std. Deviation	
ZrO <sub>2</sub> (2%)	88.44±7.90	ZrO <sub>2</sub> (2%) – Talc (2%) ( $p = 0.038$ ) ZrO <sub>2</sub> (2%) – Control ( $p = 0.039$ )
ZrO <sub>2</sub> (5%)	85.53±12.00	
TiO <sub>2</sub> (2%)	87.69±10.22	
TiO <sub>2</sub> (5%)	86.90±7.35	
Talc (2%)	73.96±10.75	
Talc (5%)	75.61±8.71	
Control	73.97±4.95	
p	0.001*	

p: Values obtained from One-way ANOVA analysis, \*Indicates a statistically significant difference at the  $p < 0.05$  level, Multiple comparisons were conducted via Tukey HSD

Data obtained from the hardness measurements are summarized in **Table 3**. Significant statistical variations were observed in the mean Vickers hardness values across the experimental groups ( $p < 0.001$ ). Moreover, when compared to any group modified with additives, the control specimens displayed substantially inferior mean Vickers hardness scores ( $p < 0.001$ ).

**Table 3: Comparison of groups by Vickers hardness values**

	Vickers (VHN)	Post Hoc Differences
	Mean±Std. Deviation	
ZrO <sub>2</sub> (2%)	591.13±34.61	ZrO <sub>2</sub> (2%) – Control ( $p < 0.001$ ) ZrO <sub>2</sub> (5%) – Control ( $p < 0.001$ ) TiO <sub>2</sub> (2%) – Control ( $p < 0.001$ ) TiO <sub>2</sub> (5%) – Control ( $p < 0.001$ ) Talc (2%) – Control ( $p < 0.001$ ) Talc (5%) – Control ( $p < 0.001$ )
ZrO <sub>2</sub> (5%)	559.25±39.86	
TiO <sub>2</sub> (2%)	572.25±64.59	
TiO <sub>2</sub> (5%)	574.13±46.13	
Talc (2%)	606.38±77.98	
Talc (5%)	567.25±41.41	
Control	448.75±32.48	
p	<0.001*	

p: Values obtained from One-way ANOVA analysis, \*Indicates a statistically significant difference at the  $p < 0.05$  level, Multiple comparisons were conducted via Tukey HSD

After performing the Vickers test on the samples, the lengths of the cracks formed on their surfaces were imaged using an overhead illuminated metal microscope (**Figure 1**). Analysis confirmed that the inclusion of talc, titanium dioxide, and zirconium dioxide yielded a microstructure that was smooth, uniform, and structurally compatible with the control group. Current findings suggest that the incorporation of additives preserved the structural integrity of the feldspathic porcelain without inducing adverse effects.

**Table 4** presents the analysis of crack lengths resulting from the hardness testing of the prepared specimens. Analysis revealed significant statistical disparities in the mean crack lengths among the groups ( $p < 0.001$ ). In particular, the 5% talc formulation demonstrated a statistically significant contraction in mean crack length when measured against the 2% zirconium dioxide ( $p = 0.001$ ), 5% zirconium dioxide ( $p < 0.001$ ), 5% titanium dioxide ( $p < 0.001$ ), and 2% talc ( $p = 0.022$ ) variations.

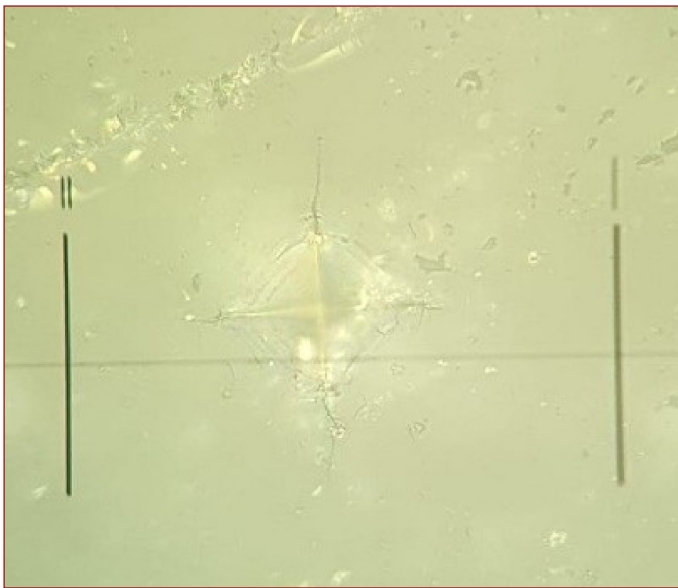


Figure 1: Crack image of the porcelain sample in the control group

**Table 4: Comparison of groups by crack length values**

	Crack Length (µm)	Post Hoc Differences
	Mean±Std. Deviation	
ZrO <sub>2</sub> (2%)	30.70±5.14	
ZrO <sub>2</sub> (5%)	32.75±1.26	
TiO <sub>2</sub> (2%)	28.29±5.28	ZrO <sub>2</sub> (2%) – Talc (5%) (p=0.001)
TiO <sub>2</sub> (5%)	31.36±6.86	ZrO <sub>2</sub> (5%) – Talc (5%) (p<0.001)
Talc (2%)	29.50±1.87	ZrO <sub>2</sub> (5%) – Control (p=0.003)
Talc (5%)	21.45±3.70	TiO <sub>2</sub> (5%) – Talc (5%) (p<0.001)
Control	25.29±2.63	Talc (2%) – Talc (5%) (p=0.022)
p	<0.001*	

p: Values obtained from One-way ANOVA analysis, \*Indicates a statistically significant difference at the p<0.05 level, Multiple comparisons were conducted via Tamhane's T2

SEM images and their respective EDS spectra for the ceramic samples are depicted in (Figures 2–9). EDS analyses revealed an increase in zirconium, titanium, and talc components and their homogeneous distribution.

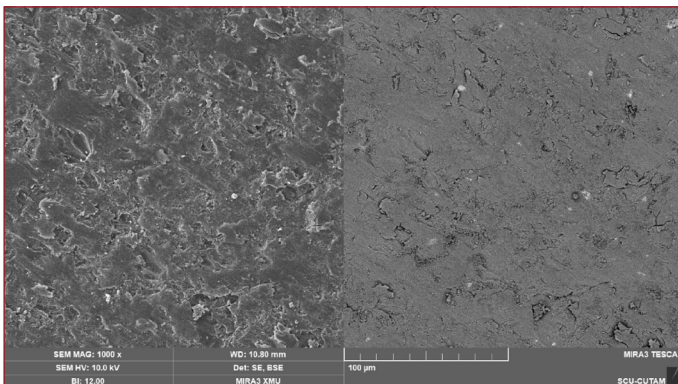


Figure 2: SEM image of the control group sample at x1000 magnification

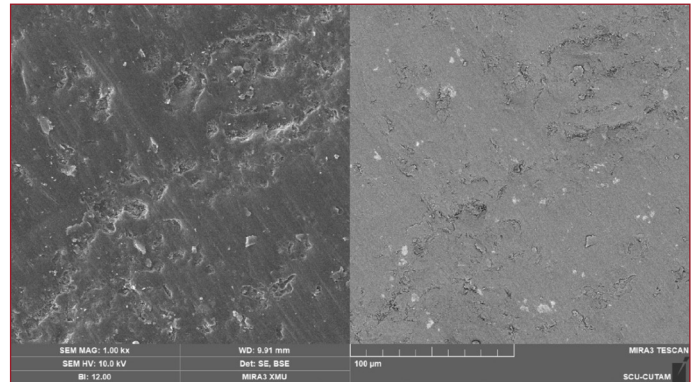


Figure 3: SEM image of the zirconium dioxide 2% group sample at x1000 magnification

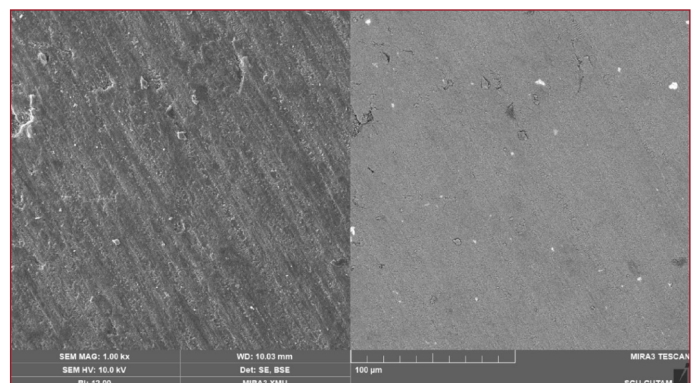


Figure 4: SEM image of the titanium dioxide 2% group sample at x1000 magnification

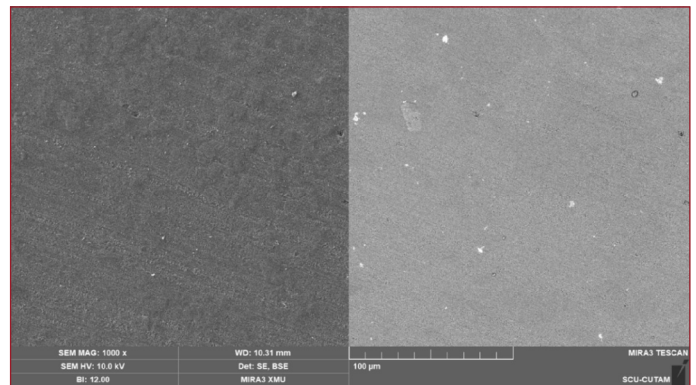


Figure 5: SEM image of the talc 2% group sample at x1000 magnification

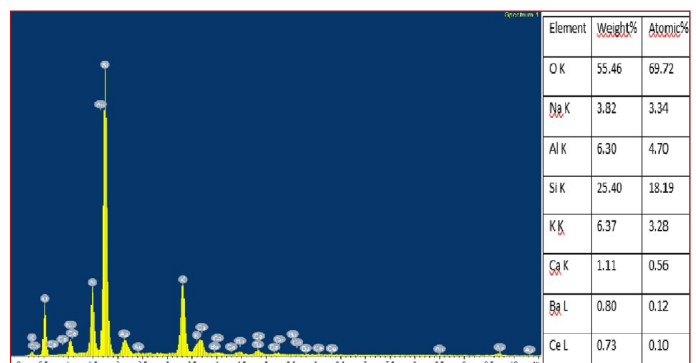
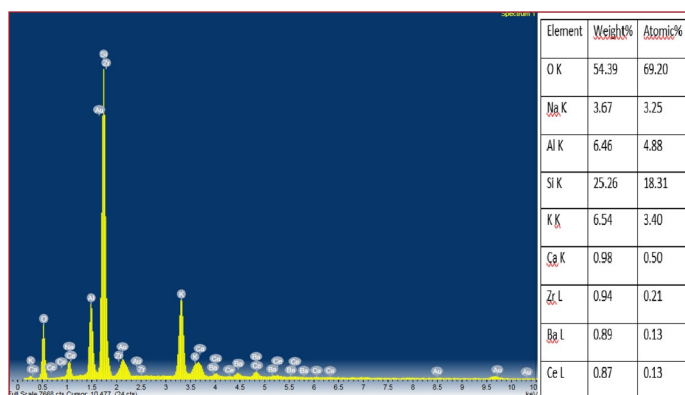
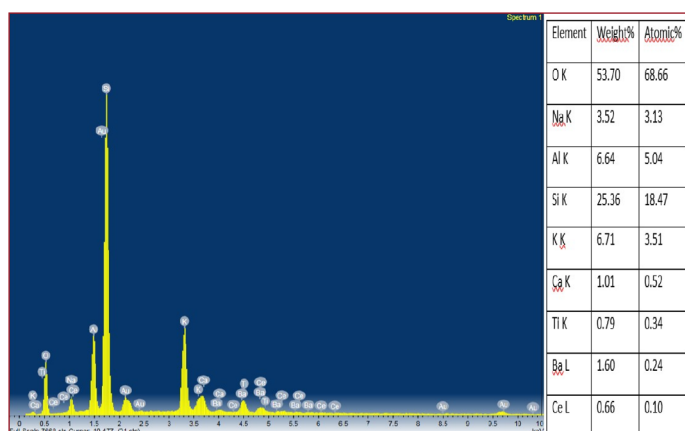


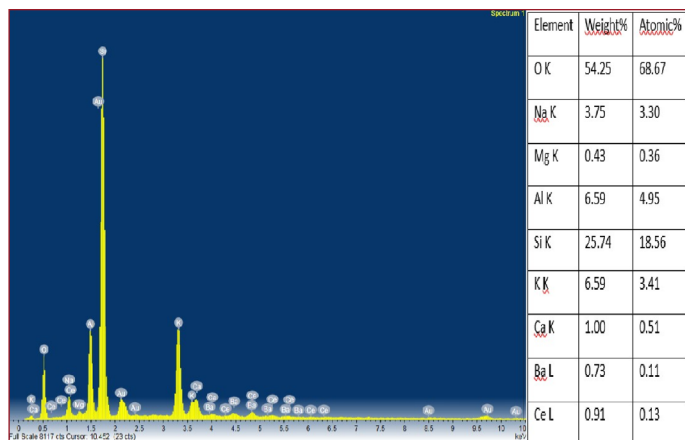
Figure 6: EDS spectrum of the control group sample and its elements



**Figure 7:** EDS spectrum of the zirconium dioxide 2% group sample and its elements



**Figure 8:** EDS spectrum of the titanium dioxide 2% group sample and its elements



**Figure 9:** EDS spectrum of the talc 2% group sample and its elements

## DISCUSSION

This *in vitro* investigation evaluated the variations in color stability, flexural strength, hardness, and crack propagation among a control group and feldspathic porcelain specimens incorporated with talc, titanium dioxide, and zirconium dioxide at concentrations of 2% and 5%. Consequently, the null hypotheses proposed in this thesis were refuted, as statistically significant differences were detected across the experimental groups.

Although the superior aesthetic properties of dental ceramics are widely accepted, their brittle structure, low tensile and shear strength cause ceramic restorations to be prone to fracture during chewing.<sup>[11]</sup> The enhancement of feldspathic porcelain's mechanical attributes is typically realized through the incorporation of supplementary materials.<sup>[4]</sup> The introduction of nanoparticles alters the physical nature of porcelain, simultaneously influencing mechanical characteristics such as density, elasticity, and overall strength.<sup>[3]</sup>

A prior investigation evaluated the color stability and mechanical behavior of feldspathic porcelain modified with mass fractions of 0.5% and 2.5% alumina-zirconia. The  $\Delta E$  value of the group with 0.5% alumina-zirconia addition was found to be the closest to 3.7, making it a clinically acceptable group. In that specific instance, the group containing 2.5% alumina-zirconia exhibited a  $\Delta E$  value exceeding the threshold for clinical acceptability.<sup>[12]</sup>

In this study, as the mass percentage of the added material increased in all groups, the  $\Delta E_{00}$  values also increased. The Talc 2% group, which exceeded the clinically acceptable threshold of  $\Delta E_{00}=1.8$ , had the lowest  $\Delta E_{00}$  value of  $2.50\pm 0.70$ . This group exhibited the minimal color shift relative to the control. Consequently, regarding resistance to color alteration, talc proved to be the most optimal additive, whereas titanium dioxide was identified as the least favorable option.

The atomic bonds in ceramic crystals are covalent and ionic in structure and do not contain free electrons. These strong atomic bonds provide stability, hardness, and resistance to chemicals to the structure. Nevertheless, these bonds also introduce drawbacks, including brittleness and reduced thermal conductivity.<sup>[13]</sup>

In particular, a statistically significant increase in flexural strength was detected in the 2% zirconium dioxide group relative to the control ( $p=0.039$ ). This concurrent enhancement in hardness and flexural strength is attributed to zirconium dioxide's influence on the dimensions and dispersion of crystal phases within the porcelain matrix. Similarly, although titanium dioxide caused a slight increase in flexural strength versus the control, this difference was not statistically significant. This phenomenon is likely attributed to the formation of extra bonding sites within the microstructure, resulting in a denser network.

Although the 2% talc group showed flexural strength values very similar to the control—indicating no significant change—a notable increase in hardness was recorded. It is postulated that this occurs because talc acts as a structural filler, optimizing microstructural homogeneity and thereby reducing internal residual stresses.

In terms of hardness, every experimental group showed significantly higher values than the control group. The peak hardness was recorded in the 2% talc specimens. This enhancement can be attributed to magnesium silicate—the primary constituent of talc—which promotes the formation

of crystalline phases and organizes the network structure. Moreover, the 2% talc group exhibited the lowest  $\Delta E_{00}$  value (indicating minimal color shift) without showing a statistically significant rise in crack length compared to the control.

The delayed failure observed in porcelains results from chemical reactions between glass and water, accelerated by stress at the tips of surface cracks where stress is concentrated.<sup>[14]</sup>

The study revealed that crack lengths generally increased in the modified groups compared to the control samples. In particular, the deviation in the 5% zirconium dioxide group was statistically significant, showing higher crack values than the control ( $p=0.003$ ). It is postulated that adding larger amounts of  $ZrO_2$  compromises the material's integrity, leading to brittleness and the development of microcracks.

Elevating the firing temperature and duration for porcelain containing talc was observed to positively impact bulk density, thereby diminishing both porosity and water absorption rates. It also had positive effects on strength values.<sup>[15]</sup>

Regarding the specimens containing talc, crack lengths were measured at  $29.50 \pm 1.87 \mu\text{m}$  for the 2% group and  $21.45 \pm 3.70 \mu\text{m}$  for the 5% group. Notably, the 5% talc group was the sole experimental condition to exhibit a reduction in crack length relative to the control. Moreover, the decrease observed in the 5% talc group was statistically pronounced in comparison to the zirconium dioxide 2% ( $p=0.001$ ), zirconium dioxide 5% ( $p<0.001$ ), titanium dioxide 5% ( $p<0.001$ ), and 2% talc ( $p=0.022$ ) cohorts.

Examination with SEM and a metal microscope revealed that the images of the groups with talc, titanium dioxide and zirconium dioxide additions were regular and homogeneous, consistent with the image of the reference group without additions. These findings indicate that the additions of talc, titanium dioxide and zirconium dioxide have no adverse effect on the feldspathic porcelain structure (Figures 1-5).

EDS analysis coupled with SEM indicated that, regardless of the additives (talc, titanium dioxide, or zirconium dioxide), all samples including the control were predominantly composed of silicon and oxygen. This finding aligns with the typical composition of the feldspathic porcelain utilized. Unlike the control group, the EDS analysis spectrum and table showed the amounts of zirconium in the groups with added zirconium dioxide, titanium in the groups with added titanium dioxide, and talc in the groups with added talc. This indicates that zirconium, titanium, and talc components were incorporated into the structure (Figures 6-9).

This thesis study has various limitations. In the study, talc, titanium dioxide and zirconium dioxide were added to feldspathic porcelain at rates of 2% and 5% by weight. Higher rates were found to improve the results. In light of these results, higher rates of additions and a larger number of samples can be used for further studies.

## CONCLUSIONS

Considering the constraints of this in vitro investigation, the following conclusions were reached:

- Statistically significant differences were detected among all  $\Delta E_{00}$  values. The titanium-added groups exhibited the maximum color change, whereas the talc-added groups showed the minimum values.
- The 2% talc group exhibited the minimum  $\Delta E_{00}$  value, approaching the threshold of clinical acceptability.
- While the flexural strength of the 2% talc group was comparable to the control, all other groups demonstrated an increase. The peak flexural strength value was recorded in the 2% zirconium dioxide group.
- The 2% zirconium dioxide group exhibited a statistically significant improvement in flexural strength relative to the control group.
- All experimental groups exhibited statistically significantly higher hardness values than the control, with the 2% talc group peaking at the highest value.
- With the exception of the 5% talc group, all other groups exhibited increased crack lengths compared to the control.
- While the 5% talc group exhibited shorter crack lengths relative to the control group, this observed reduction was not statistically significant.
- According to SEM and EDS findings, talc, titanium dioxide and zirconium dioxide were successfully integrated into the matrix, exhibiting a homogeneous distribution without compromising structural integrity.

## ETHICAL DECLARATIONS

**Ethics Committee Approval:** Ethics committee approval was waived due to the purely in vitro nature of this investigation.

**Informed Consent:** Written informed consent is not required for this study.

**Referee Evaluation Process:** Externally peer-reviewed.

**Conflict of Interest Statement:** The authors have no conflicts of interest to declare.

**Financial Disclosure:** Gaziosmanpasa University, Scientific Research Projects Unit, supported this research (Project No: 2024/12).

**Author Contributions:** All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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