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The use of çan stone processing wastes as raw material in ceramic triaxial glaze system

Çan taşı işletme atıklarının seramık üçlü sır sistemınde hammadde olarak kullanımı

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Abstract

Doğal taşlar, erişilebilirlikleri, performansları ve dekoratif nitelikleri nedeniyle giderek daha popüler hale gelen, farklı özelliklere sahip malzemelerdir. İnşaat sektöründe magmatik, tortul ve metamorfik kaya türleri, özellikle peyzaj, heykel ve seramik üretiminde sıklıkla kullanılmaktadır. Bu atıklar, toz veya ince taneler, agregalar, daha büyük taş parçaları, hasarlı bloklar veya levhalar ve sulu çamur gibi çeşitli şekillerde sınıflandırılır. Operasyon sırasında ve sonrasında ortaya çıkan sorunlar uygun şekilde ele alınmazsa, atıkların toprak, su, hava ve biyolojik kaynaklar üzerinde önemli bir etkisi vardır. Bu çalışmada, literatürde "riyolitik tüf" olarak tanımlanan ve Çan ilçesinde maden yatakları bulunan "Çan Taşı"nın üretimi sırasında oluşan işletme atıkları, üçlü seramik sır sistemleri ile oluşturulan reçetelerde bileşen olarak kullanılmıştır. Temel amaç, bu atıkların birikmesinden kaynaklanan çevresel sorunları ortadan kaldırmak ve aynı zamanda çeşitli endüstriyel sektörlerde geniş uygulama alanına sahip bir yan ürünün kullanımını sağlamaktır. Sır reçetelerine %60'a kadar eklenen atıkların ve reçetelerde kullanılan hammaddelerin kimyasal bileşimleri XRF analizi ile belirlenmiştir. Üretilen sır reçetelerinden 6 adet sır kompozisyonu karakterizasyon testleri için seçilmiştir. Üretilen sır örneklerinin karakterize edilmesinde XRD, SEM, ısı mikroskobu ve spektrofotometre cihazları kullanılmıştır. Atıklar, Şahin Madencilik Şirketinden (Çan-Türkiye) alınmıştır ve seramik sırlarının formülasyonlarına dahil edilmiştir. 1200 °C'de pişirilen numunelerde açık kahveden koyu kahveye kadar renk tonlarında şeffaf sırlar elde edilmiştir.

Keywords: Waste utilization, Traditional ceramics, Silicates, Recycling, Glaze.

Öz

Natural stones are materials with distinct properties that are becoming increasingly popular because of their accessibility, performance, and decorative qualities. In the construction industry, igneous, sedimentary, and metamorphic rock types are frequently used, particularly in landscaping, sculpture, and ceramic production. These wastes are categorized in various forms, such as dust or fines, aggregates, larger pieces of stone, damaged blocks or slabs, and stone slurry. Waste has a significant impact on soil, water, air, and biological resources if problems that arise during and after operations are not properly addressed. In this study, the operating wastes produced during the production of "Çan Stone", which is defined in the literature as "rhyolitic tuff", and has mineral deposits in Çan, Turkey, were used as components in recipes created with ceramic triaxial blend systems. The main objective is to eliminate the environmental issues brought on by the accumulation of this waste while also enabling the use of a by-product that has a wide range of applications in various industrial sectors. The chemical compositions of the waste which are added up to 60% into the glaze recipes and raw materials used in recipes were determined by XRF analysis. Among the glaze recipes produced, 6 glaze compositions were selected for characterization tests. XRD, SEM, hot stage microscope and spectrophotometer devices were used to characterize the produced glaze samples. Wastes were obtained from Şahin Mining Company (Çan-Turkey) and included in the formulations of ceramic glazes. Transparent glazes in color tones ranging from light brown to dark brown were obtained in the samples fired at 1200 °C.

Anahtar kelimeler: Atık kullanımı, Geleneksel seramikler, Silikatlar, Geri dönüşüm, Sır.

1 Introduction

Stones are one of the most readily available and abundant natural resources on the planet [1]. Natural stone owes its popularity to its performance, and decorative qualities [2]. Natural stone has been used for various purposes, such as for building stone, megaliths, ornamental stone, hunting, and grinding, throughout history [3].

A large amount of solid waste is generated during the stone processing, and a serious environmental issues and high production cost problem have arisen from the accumulation of these wastes [4],[5]. The volume of generated stone waste largely depends on the amount of the processed material (and the efficiency of the processing plant), on the type and size of the generated waste, the type and geological properties of the stone, the type of machinery used for stone processing, as well as on the applied technology of dimension natural stone processing, the degree to which the block of stone is used in order to produce the final product and the needs of the clients [2]. Low-quality natural stone may be sold as crushed stone aggregate in quarries, but other wastes, usually in larger quantities, remain and are stored in nearby open areas [1].

This results in unfavorable outcomes, such as topographical changes, land occupation, surface-and ground-water degradation, and air and visual pollution [6]. While waste increases the production costs for the company, it also pollutes the environment [7]. Some quarry wastes may form metal ions

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when they react with air and water, resulting in the contamination of the water resources near the quarry [1].

Increased consumption and, consequently, increased industrial production have resulted in a rapid decrease in the readily available natural resources, such as raw materials and energy resources [8]. The disposal or reuse of the wastes produced by this increase in production, rather than their environmental disposal, has been one of the most popular study topics.

30% of the minerals that are extracted and processed in our country end up as waste [6],[9]. Different materials can be used in production recipes since ceramic materials are multi-component systems. Natural stone wastes are the best alternative raw materials with properties that can be utilized in ceramic recipes. Important steps in this direction include finding new components to use in the recipes for ceramic production, developing new material resources, and conducting studies on recycling wastes.

Numerous studies have been conducted on the recycling of natural stones and other ceramic wastes. Segada˜es et al. produced clay products out of the leftover production waste from marble and granite. They discovered that some sinterable product properties were improved at lower temperatures [10],[11]. According to the study titled "Evaluation of Natural Stone Production and Processing Plant Wastes" by Aydın and Karakurt, environmental problems can be avoided through effective waste utilization studies in various fields [11],[12]. Ceramic tile waste can lower production costs in the construction industry, as discovered by Suchithra et al. [12],[13]. In a 2022 study by Luo et al. [13],[14], granite powder and waste marble were used in the production of architectural glass ceramics. Their findings showed that, as waste marble content increased, the main crystal phase of glass ceramics changed from anorthite to wollastonite, and the flexural strength of the glass ceramic also increased. Aside from traditional ceramic raw materials, numerous studies have been conducted on the use of waste as an alternative raw material to produce ceramic glazes with varying technological and visual properties [15]-[21]. Volcanic rocks, tuffs, volcanic ashes, and solid wastes produced during or after production in various industries are among the main sources of such raw materials [21],[22].

Glaze is an essential component of traditional pottery as well as in industrial and artistic ceramic production. Glazes are mixture of crystalline materials capable of erosion resistance and suitable compatibility with aluminosilicate substrates. It is a special sort of glass differing from window glass and glass ware in its lower thermal expansion and higher alumina content, which increase its viscosity and help it to adhere to the clay body [22],[23].

The compositions of glazes are based on aluminosilicate glass with combinations of natural and synthetic materials [23], [24]. The production and development of glaze recipes and even the systems used glaze coloring are important. The line blend, triaxial blends and square or quadriaxial blends are the important methods using to produce new glaze recipes. Triaxial blending system is an old process, mainly used for intermixing of three existing glazes to create a new, forth glaze. It is a very useful and functional method for mixing glazes or colorants or to obtain a new glaze composition with three different glaze raw materials [24],[29]. New glaze compositions can be produced using this method by using raw materials which melt and vitrify at specific temperatures. It demonstrates both the effects of each raw material on the glaze composition and the characteristics of the glaze surfaces formed by the raw materials in the specified ratios.

In this study, the solid waste produced during the quarrying and processing of the rhyolitic tuffs known as "Çan Stone" in the district of Çanakkale-Çan, Turkey, was used as raw material in the production of ceramic glaze. The primary objective of this work is to study the potential use of Çan stone cutting waste in the production of ceramic glaze, which would reduce both the environmental impact and the production cost. Natural stone wastes from the plant account for a significant portion of all wastes, and since they are not biodegradable, the wastes generated there pose a significant environmental problem.

It is aimed to recycle the remaining waste remaining after production and processing, which would provide alternative cheap raw materials to the ceramic sector by developing a suitable process for reuse as raw material and providing a solution to environmental problems by recycling waste in this way.

These rhyolitic tuffs have light yellowish, beige, white, and brown color tones and are known locally as "Çan Stone,". They are rocks that frequently experience iron oxidation as a result of hydrothermal alteration. Beige and yellow's darker hues go well with a linear, haloed, or patterned image. It is preferred as cladding and decorative stone with these patterns. Because they contain a variety of colors and patterns, are lightweight, and require little processing, Çan stone tuffs are suitable for use as lightweight building stones in exterior claddings [29], [30]. The amount of silicon in the mined can stone extracted by blasting and the distribution of hairline cracks indicate which production technique is appropriate. Çan stone waste was gathered from a quarry owned by a private company in the Çan district of Çanakkale province in northwest Turkey. After the stones are extracted from the quarry site, they are transported to the operation Figure 1(a). The undamaged, large stones are separated for slab cutting Figure 1(b).

(a)

(b)

Figure 1(a): Çan stones from the quarry. (b): Çan stone blocks cut in the factory.

To prepare damaged stones for rolling, workers break damaged stones with hammers Figure 2(a). Small pieces with no economic value that are produced during product breaking with a hammer and chipping with hand tools or machine equipment are the wastes used in the study Figure 2(b). Production tasks such as plate cutting, tumbling, and other operations are carried out in the furnace where the waste is supplied. Crack-free blocks are required for the slab process. As a result, workers use hammers to reduce the size of blocks that are prone to hairline cracks are reduced before sending them to other production channels.

(a)

(b)

(c)

Figure 2(a): Size reduction process with hammer.
(b): Tumbling process. (c): Çan stone wastes after reduction.

2 Materials and methods

In this study, ulexite ($NaCaB_5O_9.8H_2O$), red clay and stone waste were used as raw materials in the triaxial system stoneware glaze compositions.

In the first stage of the research, small pebbles were grounded when wet in a ball mill with a dry matter capacity of 1.5 kg. Following grinding, the dried waste powders were subjected to grain size and hot stage microscopy analyses. The wastes were mixed with water, applied to the stoneware body, and fired at 1200 °C to observe the surface effect of firing.

The recipes for the glazes that would have been produced were determined using the Triaxial Blend Method. The triaxial blend is a technique of creating a glaze, pigment, or primer from three different materials. This method tests the effects of three different raw materials on a three-axis system. Each corner of the triangle represents 100% of the material. Each side of the triangle is the line blend of the materials at its ends, and the intersections inside the triangle represent combinations of all three materials. So, the result is three-line blends, plus all the combinations [1],[32], (Figure 3).

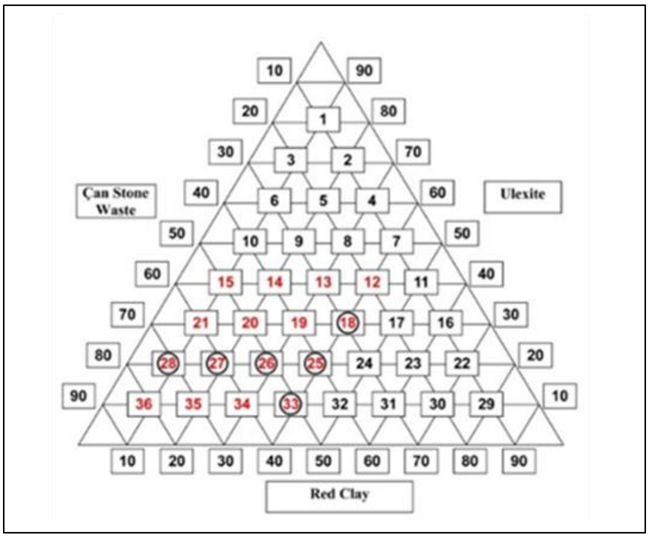


Figure 3. Triaxial glaze blend system.

The firing temperature was set as 1200 °C. Ulexite lowers the temperature and facilitates easy melting in recipes that contain it [32]. For this reason, composition points containing ulexite up to a maximum of 40% have been studied. First, the triple system was used to prepare 16 glaze recipes in the chosen areas in Figure 3. The ratios of the glaze compositions prepared are given in Table 1.

Table 1. Glaze compositions in triaxial system.

Recipe No	Raw Materials (wt. %)		
	Çan Stone Waste	Ulexite	Red Clay
R12	20	40	40
R13	30	40	30
R14	40	40	20
R15	50	40	10
R18	30	30	40
R19	40	30	30
R20	50	30	20
R21	60	30	10
R25	40	20	40
R26	50	20	30
R27	60	20	20
R28	70	20	10
R33	50	10	40
R34	60	10	30
R35	70	10	20
R36	80	10	10

Chemical analysis of the waste powder and other raw materials was carried out by Rigaku ZSX Primus X-ray fluorescence (XRF) instrument. In order to determine the thermal behavior of the glaze recipes obtained, hot stage microscopy measurements were conducted.

After weighing the glaze compositions, the batches were, first of all, milled for 30 minutes. The resultant slurries were sieved through 100 µm and their liter weight (1400 gr) and viscosity values were controlled. Then, they were applied onto stoneware bodies. Optical parameters of the colored glazed samples, which were fired at 1200 °C directly, were investigated by Konica Minolta CM-2300d spectrophotometer. All firings were conducted in a laboratory type Nabertherm electrical furnace. The firing regime is 150°C/h, and the firing time is 8 hours.

For the determination of phase formations occurred as a result of the waste incorporated into bodies, X-Ray diffraction analysis with a Rigaku Miniflex 600 diffractometer by using CuKα radiation was conducted. Microstructural studies were done with a Zeiss Supra 50 VP model scanning electron microscope.

3 Results and evaluation

Chemical analysis of the raw materials and stone wastes used in the study are presented in Table 2. Figure 4 shows the particle size distribution of the used waste after grinding.

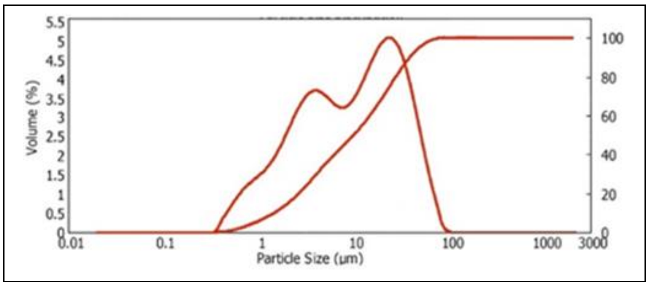


Figure 4. The particle size distribution curve of stone waste.

As it seen from the Table 2, the waste is high in quartz content, followed by aluminum oxide.

The average particle size of the waste was measured as 9,864 µm.

Figure 5 shows the waste after it was applied to the stoneware body (diameter = 9 cm) and fired at 1200 °C. A reddish-brown matte surface was obtained after applying Çan stone waste to the surface and firing it without any additives.

Figure 6 shows the XRD analysis graph of the waste fired at 1200 °C, which is the firing temperature used to produce the glazes. Quartz was identified as the primary phase in the structure of the waste.

Figure 5. Appearance of Çan stone waste fired at 1200 °C.

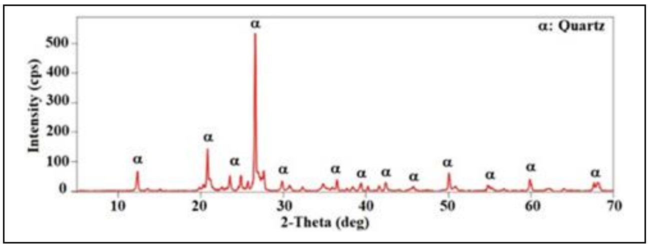


Figure 6. XRD spectra of the stone waste.

From Figure 7 the hot stage microscope analysis of stone waste indicates the sintering and softening temperatures of waste being 1126 °C and 1394 °C respectively. Differences in behavior, characteristic points, and temperatures can be observed with hot stage microscopy, and the results provide an idea about the material suitable for use in ceramic systems.

The glaze compositions within the areas marked in the triple glaze system (Figure 3) were studied.

Among these recipes, R12, R18, R25, R26, R27, R28 and R33 coded glazes were selected, in which the waste was added at increasing ratios, and which gave the most visually effective surface images after firing (Table 3). these glazes were evaluated as two separate groups.

Group I contain the glaze compounds coded R18, R25, and R33. In this group, the rate of red clay (40%) remains constant, while the rate of ulexite decreases and the rate of Çan stone waste increases. This increase varies between 20% and 50%.

Group II contains the glaze compounds with the codes R26, R27, and R28. In this group, according to the system, the rate of ulexite remained constant at 20%, whilst the ratio of red clay decreased, and the ratio of Çan stone waste increased. This increase varies between 40% and 70%.

Table 2. Chemical analysis of the raw materials and stone waste used in the glaze recipes (wt.%).

Raw Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	B_2O_3	*L.O.I.
Çan Stone Waste	69.62	15.95	2.85	0.26	-	1.20	5.61	0.2645	-	4.25
Ulexite	3.26	0.71	0.11	22.68	1.83	5.45	-	-	38.28	27.6
Red Clay	61.47	18.16	7.31	1.23	1.62	0.78	2.53	1.17	-	5.71

*****: Loss on ignition.

Table 3. Glaze compositions Glaze selected for characterization tests in triaxial system.

Glaze Recipe No	I. Group Glaze components (%)			Glaze Recipe No	II. Group Glaze components (%)		
	Çan Stone Waste	Ulexite	Red Clay		Çan Stone Waste	Ulexite	Red Clay
R18	30	30	40	R26	50	20	30
R25	40	20	40	R27	60	20	20
R33	50	10	40	R28	70	20	10

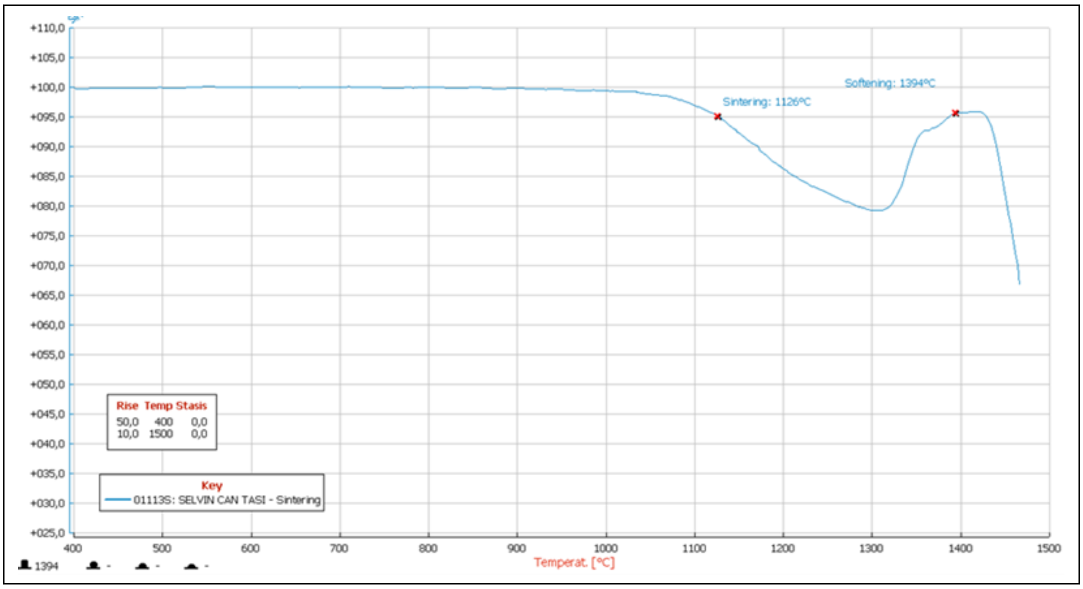


Figure 7. The hot stage microscope curve of stone waste.

The effect of stone waste addition in triaxial glaze compositions on the color and texture can be seen from Figure 8. The diameter of the plates is 9 cm.

Figure 8. Surface images of glazes prepared with Çan stone waste after firing at 1200 °C (Diameter: 14 cm).

The optical parameters and gloss (20° and 60°) values of waste (SDT) and waste added glaze products were shown in Tables 4 and 5.

When the waste, prepared as an aqueous glaze suspension and coded as STD, was applied to the stoneware body and fired at 1200 °C, it created a reddish-brown matte glaze surface. When the recipes of glazes 18, 25 and 33 in the triaxial glaze system are examined; the ratio of red clay is constant in these three glazes. The ratios of waste and ulexite raw materials vary. While the amount of waste in the recipe increases, ulexite decreases. This affects the whiteness, redness (a*) and brightness (L*) values of the resulting glazes. In this group, the amount of iron oxide in the waste (4.48%) is thought to be effective in this change.

In the glazes numbered 26, 27 and 28, which are in the II. Group chosen within the triaxial glaze system; the ulexite ratio is constant, while the waste and red clay ratio is variable. While the waste ratio increases, the red clay ratio decreases. Despite the increase in the waste ratio, it is thought that the decrease in red clay containing 7.31% Fe_2O_3 causes an increase in L* values and a decrease in a* value.

The surface of R33 glaze is opaque brown. The R25 glaze produced a glossy dark red-brown surface effect, and the R18 glaze produced a textured, light honey-colored surface effect. There were no glaze defects such as cracking, spalling, etc. on the surface. It has been observed that the color and surface appearance of the glazes R26 and R27 are particularly effective. The body and glaze compatible with each other. The results suggest that, in terms of visual effects, R18, R25, R26, and R27 glazes can be easily used in artistic and industrial ceramic products.

Figure 9 presents the results of hot stage microscopy analyses of the chosen glaze recipes and Çan Stone waste.

In the first group, it was observed that the melting temperatures of the R25 and R33 coded samples increased, while the amount of ulexite decreased gradually compared to the sample coded R18 and the amount of waste increased. In the second group, an irregular change was observed in the sintering and melting temperatures of the R27 and R28 coded samples, where the red clay content decreased, and the waste ratio increased by keeping the ulexite amount constant. While more SiO_2 enters the system with the increasing amount of waste, the total amount of iron oxide (Fe_2O_3), which acts as a smelter in the system, has also decreased with the decrease in the amount of red clay. The XRD patterns of fired glazes coded as R18, R25-28, R33 and R36 are given in Figure 10.

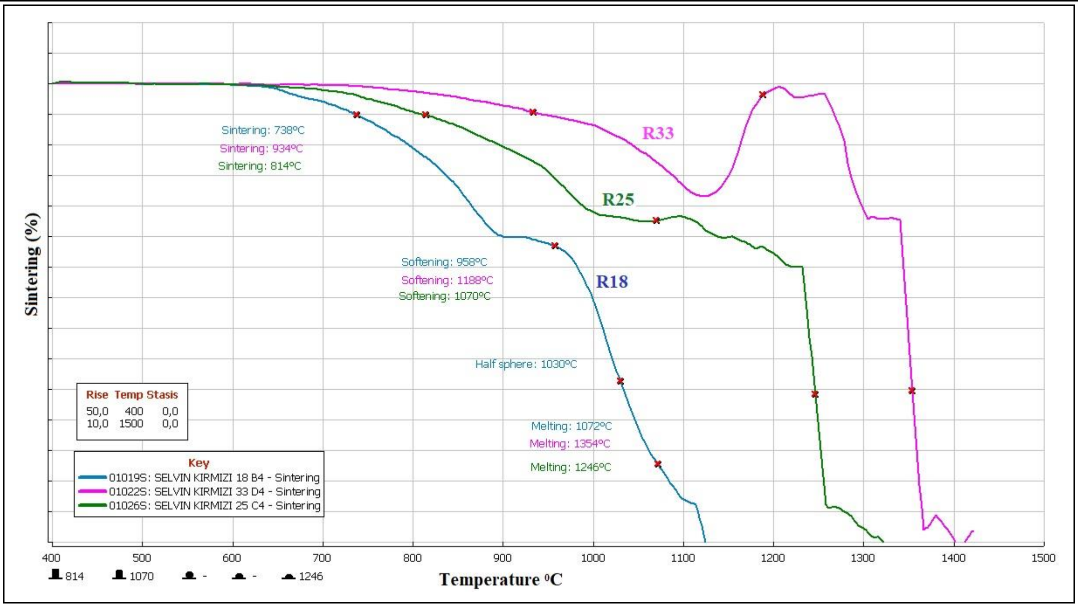
Figure 10 shows the X-ray diffraction patterns of the wastes. The diffraction patterns of the wastes have only peaks of quartz (SiO_2). The results of the X-ray diffraction analysis agree with the Chemical analysis results. Figure 11 shows the changes in the final microstructures of the triaxial glaze compositions with waste addition.

Table 4. Çan stone waste and the color and gloss values of the glaze compositions in Group I.

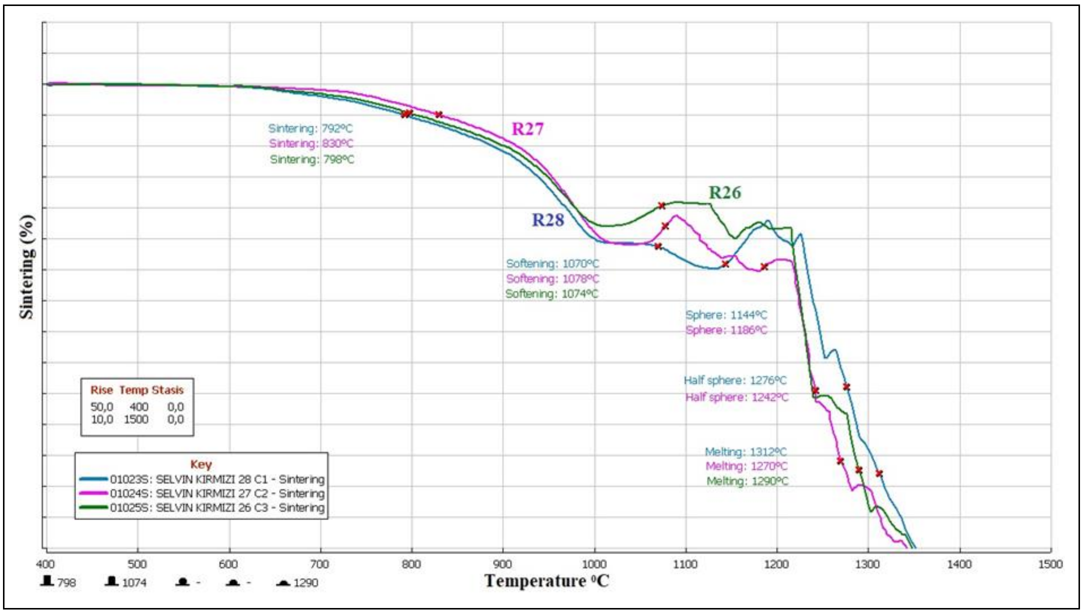
Glaze Recipe	Color Parameters			Brightness		
No	L*	a*	b*	20°	60°	85°
STD	39.64	12.47	11.35	0.4	3.7	1.8
R18	46.09	7.56	26.99	40.9	65.6	48.7
R25	26.58	2.12	0.93	11.1	38.6	33.4
R33	32.00	2.61	2.86	3.6	25.8	23.3

Table 5. Çan stone waste and the color and gloss values of the glaze compositions in Group II.

Glaze Recipe	Color Parameters			Brightness		
No	L*	a*	b*	20°	60°	85°
STD	39.64	12.47	11.35	0.4	3.7	1.8
R26	30.35	8.95	7.89	15.1	56.9	30.7
R27	43.03	8.50	22.62	5.0	18.1	11.9
R28	46.09	7.56	22.99	40.9	65.6	48.7

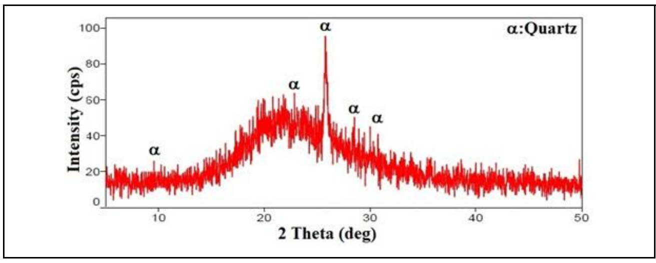


(a): 1. Group.

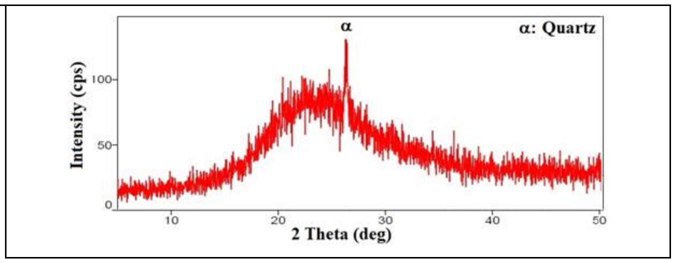


(b): II. Group.

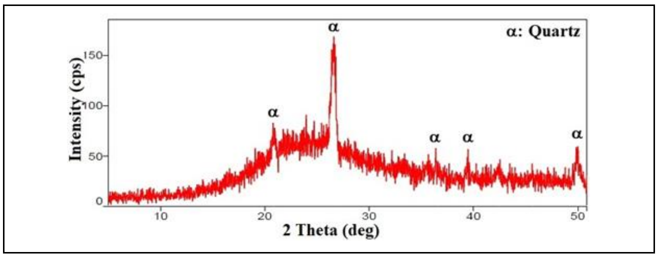
Figure 9. Relative hot stage microscope curves of glazes.



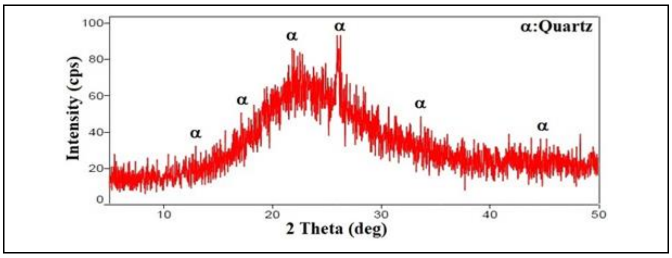
(a): R18.



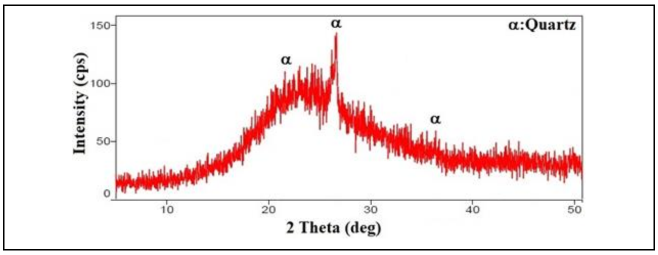
(b): R25.



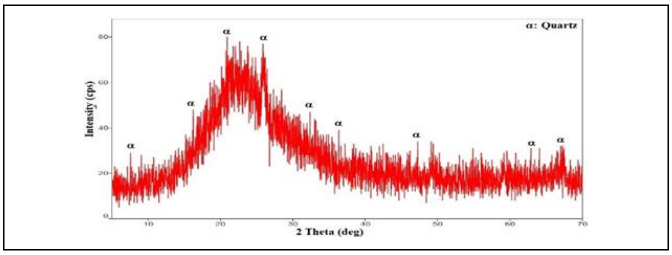
(c): R33.



(d): R26.

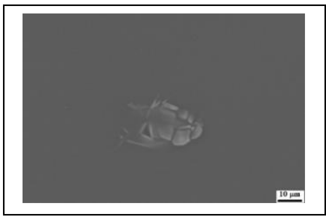


(e): R27.



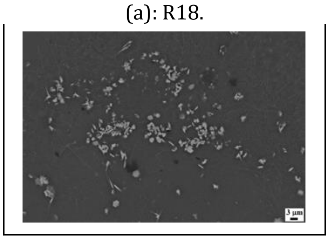
(f): R28.

Figure 10. XRD patterns of fired glazes.

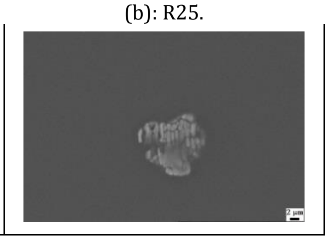


(a): R18.

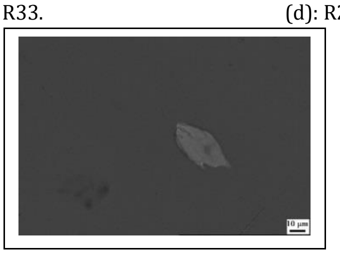
(b): R25.



(c): R33.



(d): R26.



(e): R28.

Figure 11. SEM micrographs taken from the surface of the fired glazes coded as R18 Mag: (2.55 K X), R25 Mag: (6.36 K X), R33 Mag: (2.49 K X), R26 (Mag: 4.42 K X), R28 (Mag: 1.57 K X).

The distribution of these crystalline phases can be observed in the SEM microstructure analysis of the sample coded R33, where the most crystalline phases were observed in the XRD analyses due to the high iron content from the waste incorporation [33].

At the end of the study, ceramic artworks produced by using R18, R25, R33, R26, R27, R28 glaze recipes presented in Figures 12 and 13.

(a): R26-R27(Height: 12 cm).

(b): R26 (Height: 8 cm)

(c): R18-R25 (Height: 8 cm), (Design and photos: Hande Özge ÖZKUL).

Figure 12. Artistic ceramics produced by waste added glazes.

Figure 13. Ceramic wall panels produced using glaze coded R25 (Design and photo: Hande Özge ÖZKUL).

The glazing process was carried out by dipping technique. Glazing with the dipping technique is the process of immersing ceramic bodies in a glaze for three to five seconds. This is the fastest way to glaze ceramics in even layers, but potters also use it to form a base for other finishing techniques. Dipping your ceramic piece is the fastest way to cover part or all of your piece in a smooth coat of glaze. The goal with dipping is to create the smoothest coat of glaze possible [34],[35].

The design aims to create a 3D effect in 2D ceramic tiles (Figure 14). It is aimed to obtain an effective result by gradually entering the prepared waste-added ceramic glaze into the interstitial spaces on the transitional surface. In order to convey the dimensional effect of this artistic reactive effect surface to the other side, it is viewed from 3 different angles. Glaze accumulated in the hollow areas and a bitter brown surface was obtained. On the protruding surfaces, a lighter brown surface was obtained.

When the waste is directly grounded and applied to the ceramic body surface and fired, it creates a red brown-dark brown matte surface with a reinforced lining feature. It has been observed that when the Çan stone waste and glaze forming and melting raw materials are used and the amount of waste is increased, the colors on the glazed surfaces change, the colors become darker and different surface textures are formed.

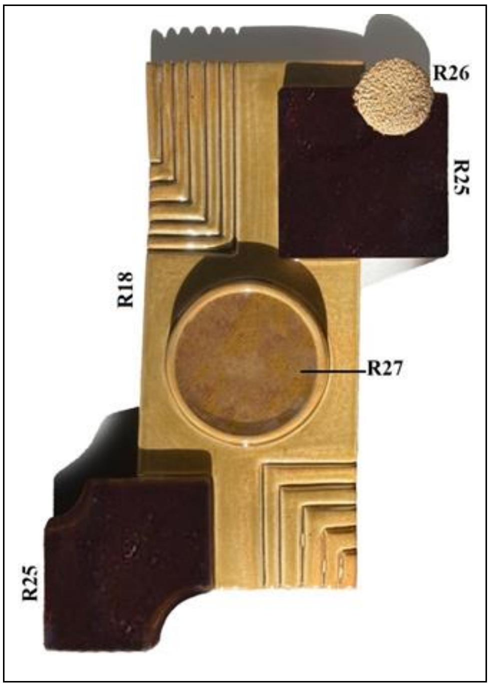


Figure 14. Forming by casting method, glazes coded as R18, R25, R26, R27, Mixed glazing method, Pouring and spraying, 1200 °C (Design and photo: Hande Özge ÖZKUL).

Individual color and texture effects have been obtained in ceramic designs in which glaze recipes produced with the addition of waste are used. It was observed that the produced glazes with waste additives were of suitable fluidity for the dipping technique and a homogeneous glaze application was obtained.

4 Conclusions

Utilizing characterized waste presents benefits in cost reduction, environmental mitigation, exploration of alternative raw materials, and innovation in product formulation. With dwindling raw material reserves in the industry, recycling natural stone waste, particularly Çan stone waste indigenous to our country, becomes imperative. This study characterizes Çan stone waste and incorporates it into ceramic glaze compositions, demonstrating its potential as a viable alternative raw material.

This study explores the utilization of waste generated during the production of "Çan Stone," a type of rhyolitic tuff abundant in Çan, Turkey, as a raw material in ceramic glaze compositions. Natural stone waste, a by-product of stone processing, presents significant environmental challenges due to its non-biodegradable nature and potential for polluting soil, water, and air resources. This research aims to address these environmental issues while also reducing production costs by recycling the waste in the ceramic industry.

The study employs a triaxial system to create glaze recipes that incorporate Çan stone waste, red clay, and ulexite. The waste is subjected to various analyses, including XRF analysis for chemical composition, XRD analysis for phase identification, hot stage microscopy to determine sintering and softening temperatures, and SEM for microstructural examination. The results indicate that Çan stone waste is predominantly composed of quartz, making it a suitable candidate for glaze production.

Notably, some glazes exhibit appealing color and texture effects, making them suitable for both artistic and industrial ceramic applications. The R33 glaze presents an opaque brown surface, while R25 showcases a glossy, dark red-brown effect. R18 offers a textured, light honey-colored appearance. Glaze defects like cracking or spalling were absent. R26 and R27 glazes demonstrate particularly effective color and surface characteristics. Both body and glaze exhibit compatibility. These findings suggest that R18, R25, R26, and R27 glazes are suitable for artistic and industrial ceramic products due to their appealing visual effects.

Additionally, the study demonstrates that the addition of waste affects the melting and sintering temperatures of glazes, which can be attributed to changes in the composition of raw materials. Sixteen different glaze compositions containing varying proportions of waste were produced in the triple glaze system. Six recipes with the highest color, texture, and aesthetic effect were selected and converted into product forms. Matte and transparent glazes with high coverage and no surface defects were obtained. It has been observed that up to 60% of Çan stone waste can be used as an alternative raw material in glaze production. No surface cracking, spalling, or other significant errors occurred.

The aim is to increase the interaction in industrial production and pave the way for the use of Çan stone waste in different areas. In this way, while contributing to environmental solutions, a low-cost, sustainable raw material will be provided to the ceramics industry.

Overall, this research provides valuable insights into the recycling of natural stone waste for ceramic glaze production. By repurposing waste materials, the ceramic industry can potentially reduce its environmental impact and production costs while creating innovative and visually appealing ceramic products.

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6 Author contribution statements

Selvin YEŞİLAY has contributed to a range of aspects, from the inception of the idea to sourcing materials, developing recipes, writing literature, conducting characterization tests, and interpreting the results. Hande Özge ÖZKUL has worked in various areas, including the preparation and production of glaze compositions, designing ceramic products, and conducting literature research. Münevver ÇAKI has made contributions spanning the inception of the idea, the evaluation of obtained results, and the development of recipes and products.

7 Ethics committee approval and conflict of interest statement

“There is no need to obtain permission from the ethics committee for the article prepared”.

“There is no conflict of interest with any person / institution in the article prepared”.

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