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Research Article

Utilization of ceramic waste in the production of Khorasan mortar

H. Selim Şengel [a,*], Mehmet Canbaz [a], Ersin Güler [b]

[a] *Department of Civil Engineering, Eskişehir Osmangazi University, 26480 Eskişehir, Turkey*
[b] *Department of Construction Technology, Sivrihisar Vocational School, Eskişehir Osmangazi University, 26600 Eskişehir, Turkey*

ABSTRACT

Khorasan mortar was used in almost all of the historical structures in the geographical area of turkey. It is still used in the renovation of these structures. Water, lime, baked clay is used in the production of Khorasan by breaking and grinding. Crushed brick and tiles are preferred as baked clay. In this study, the usability of ceramic wastes as baked clay was investigated. An important part of ceramic production is made especially in Eskişehir and its vicinity. 10% of ceramic production shows up as wastes because of various reasons. These wastes which are under 20 mm are crushed in the jaw breakers and these which are under 150 mm are grinned in grinders, transformed to powder and then mixed with hydrated lime and water in various proportions, in this way Khorasan mortars are obtained. In mortar production, crushed ceramic-ceramic powder ratio, ceramic-lime ratio were changed and the most suitable ratios were tried to be found. Samples taken from these mortars which are 4 cm x 4 cm x 16 cm in size are removed after a day from the mold and kept in humid environment. Physical and mechanical properties such as unit weight, ultrasonic pulse velocity, bending strength, compressive strength of the mortar were determined. As a result of the experiments, the unit weights range was between 1.5–1.65 kg/dm^3, the ultrasonic pulse velocity rates range from 1.3–1.9 km/h, the range of bending strengths was from 0.25–1.05 MPa, and compressive strength has changed in the range of 7.5–10.5 MPa. With the work done, it is recommended to use a high percentage of lime while using ceramic wastes in the process of producing Khorasan mortar.

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1. Introduction

The Khorasan mortar which is prepared by using crushed brick and lime was the most important binding material used in historical structures. Before making any intervention to historical structures, it is necessary to know their characteristics and produce mortar and plaster with these characteristics. Interventions made to historical structures with materials such as cement increase the problems. Therefore, a large number of studies have been carried out on the properties of mortar and plaster used in historical structures (Böke et al., 2004).

The word Khorasan was taken from the Khorasan region in eastern Iran and "Cocciopesto" in the Roman period, "Surkhi" in India, and was named as "Homra" in the Arab countries (Erdoğan, 2003). The Khorasan mortar is often used in the Middle East and Anatolian civilizations where brick structures are very advanced. In the Byzantine, Seljuk and Ottoman structures, there was a wide range of Khorasan mortar usage (Çamlıbel, 1998). The characteristics of the Khorasan mortar are equivalent to today's concrete. Although it is called Horasan but in the study of historical structures, it is stated that the phrase "Khorasan concrete" is more accurate (Akman et al., 1986). Khorasan mortar is a composite of lime, crushed and dust of brick (Özgüleş, 2019). Khorasan mortar as interface material has gained experience in more than ten centuries (Kasimzade et al., 2019a). The studies on the determination of the Khorasan mortar and its properties are still up-to-date (Kasimzade et al., 2019b, Uygunoğlu et al. 2019).

* *Corresponding author*. Tel.: +90-222-239-3750 ; Fax: +90-222-229-0535 ; E-mail address: ssengel@ogu.edu.tr (H. S. Şengel)
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Ceramic, by definition, is the process of baking the compounds made with non-organic materials giving them a shape by various methods, with or without glazing until hardening (Thickgrass et al., 2015). Baking can also be defined as the hardness of the formed ceramic under the effect of temperature (Arcasoy, 1983).

In this study, the usability of ceramic wastes as baked clay was investigated. An important part of ceramic production is made especially in Eskişehir and its vicinity. 10% of ceramics production shows up as wastes because of various reasons. These wastes which are under 20 mm are crushed in the jaw breakers, these which are under 150 mm are grinned in grinders and transformed to powder, then mixed with hydrated lime and water in various proportions, in this way Khorasan mortars are obtained. In mortar production, crushed ceramic-ceramic powder ratio, ceramic-lime ratio was changed and the most suitable ratios were tried to be found. The study showed that ceramic wastes can be used in the production of Khorasan mortar. However, in order to use ceramic wastes in the production of Khorasan mortar, it should be determined not only mechanical and physical properties but also durability properties.

2. Materials and Experimental Method

Hydrated lime: The bagged powder lime which was produced by Adaçal A.Ş. in which the calcium lime in the structure of the extinct limestone is 80 and suitable with the TS EN 459-1 is used. Chemical properties are given in Table 1.

Table 1. Chemical properties of hydrated lime.

Active $Ca(OH)_2$, %	Humidity, %	SiO_2, %	MgO, %	SO_3, %	R_2O_3, %
80-85	0.5-1	0-0.1	0.2-0.4	0.1-0.3	0.1-0.2

Crushed ceramic and powder: Crushed ceramics used in the experiments were obtained from the ceramics produced by Eczacıbaşı Vitra Artema Bilecik Bozüyük factory. They are broken up to 20 mm in size in Jaw crushers. In order to obtain the ceramic powder, these crushed particles which were milled in a ball mill were sifted by a 150 mm sieve. Chemical properties of ceramic wastes are given in Table 2.

Table 2. Chemical properties of ceramic waste.

Content	%	Content	%
SiO_2	63.45	CaO	8.18
Al_2O_3	13.98	Na_2O	0.90
Fe_2O_3	5.39	K_2O	2.43
TiO_2	0.77	SO_3	0.10

In the production of Khorasan mortar, 0-2 cm crushed ceramic and 0-150 cm ceramic powder are used as crushed baked clay and powder. Hydrated lime is used as lime. The mixing ratios are given in Table 3. 4 cm x 4 cm x 16 cm specimens were taken from the produced Khorasan mortar. After 1 day, specimens removed from their molds were covered with wet cloth. The cloth is kept wet by occasional soaking. After 7 and 28 days of production, the physical and mechanical characteristics such as unit weight, ultrasonic, bending and compression tests were carried out, and as a result the unit weight of the mortar, ultrasonic transition velocity, bending strength, compressive strength were determined.

Table 3. Mixing ratios.

Crushed ceramic, gr	Ceramic powder, gr	Water, gr	Hydrated lime, gr	Baked clay powder/lime
800	800	800	400	2
800	600	800	600	1
800	400	800	800	0,5

3. Results and Discussions

Fig. 1 shows the change in the unit weights of the Khorasan mortar produced with waste ceramics. In Fig. 1, when the ceramic powder-lime ratio increased in 7-day samples, the unit weight decreased by 2%, While in the 28-day specimens increased by 2% and decreased by 3% at higher ratios. In general, it was noticed that the 28-day specimens have higher unit weights. Also the addition of ceramic dust decreased the unit weight, as the density of the ceramics was much lower. Since the shrinkage of specimens is higher in older ages, the unit weight increases a little bit as their ages increase too.

In Fig. 2, the changes in ultrasonic pulse velocity are observed depending on the ceramic powder-lime ratio of the Khorasan mortar. In Fig. 2, when the ceramic powder-lime ratio increases, the ultrasonic pulse velocity increases by 15% in the 7-day samples, while the 28-day samples increases by 4%. As the increase of ceramic dust increases the amount of silicate, aluminate and iron in the environment, the compounds that can react with the lime have increased, so that the increase in the compactness increases the ultrasonic pulse velocity. In addition, it's noticed that the ultrasonic pulse velocity of the 28-day specimens is higher than the 7-day specimens by about 30%. This suggests that the products of hydration reactions continue to increase in the compactness of the microstructure, thereby increasing the ultrasonic pulse velocities.

Fig. 3 shows the change in values of the dynamic elastic modulus obtained depending on the unit weight and the ultrasonic pulse velocity of the samples. When examining Fig. 3, the increase of ceramic powder in 7-day samples increased the dynamic elasticity modules by around 30%, while it increased by only 6% in 28-day samples. This increasing rate decreases as the ceramic powder and lime's hydration reaction speed decreases in advanced ages. The dynamic elasticity modules of the 28-day specimens showed an increase of 90% compared to the 7-day specimens. This increase rate has increased, especially since the change in unit weight and ultrasonic pulse velocity is evaluated together.

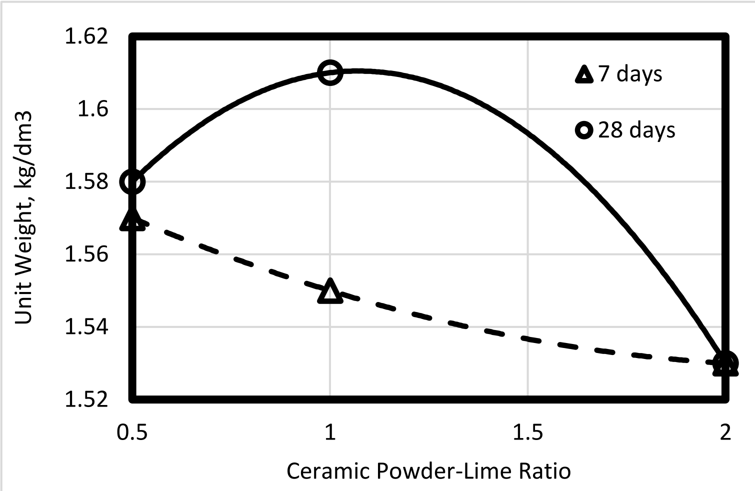

Fig. 1. Unit weight values of specimens.

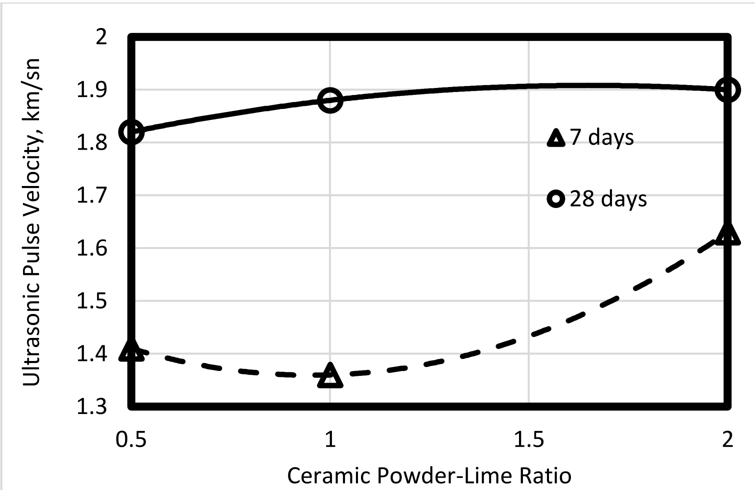

Fig. 2. Ultrasonic pulse velocity values of the specimens.

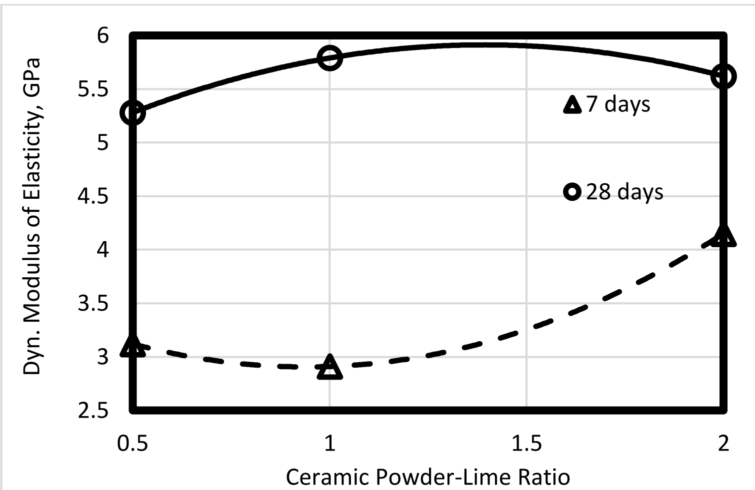

Fig. 3. Dynamic modulus of elasticity values of specimens.

Fig. 4 shows the change in bending strength of the Khorasan mortar produced with ceramic wastes. As the ceramic powder increased in 7-day samples when examined in Fig. 4, there was no remarkable +1% change rate in the bending strength. However, in 28-day samples, the increase in ceramic dust-lime ratio increased the bending strength by 9%. From that it can be said that the reactions made by the ceramic powder fill the gaps in the microstructure and As a result of obtaining more filled sections the bending strength increases. It is observed that only 30% of the 28-day bending strength can be reached at early age.

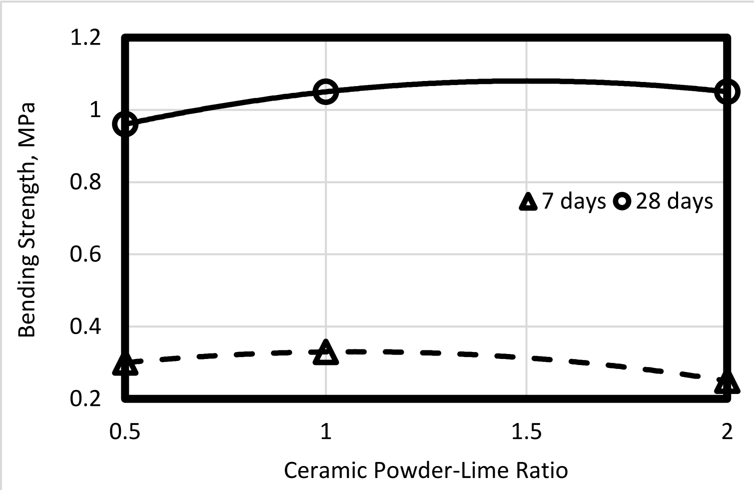

Fig. 4. Bending strength values of samples.

In Fig. 5, it's observed that the change of compressive strength depends on the ceramic dust-lime ratio of the Khorasan mortar. In Fig. 5, the increase of ceramic powder increases the compressive strength by up to 7% in 7-day samples. In 28-day samples, the ceramic powder-lime ratio was 1 and increased by 11% compared to the other ceramic powder-lime ratios. In terms of strength, the ideal ceramic powder, lime mixing rate is 1. Considering the Time-dependent strength development, it has been observed that about 80% of the 28 days compressive strength values are achieved in 7 days. At an early age, significant values such as 8 MPa were reached, while in 28 days the ceramic powder-lime ratio was 1, and compressive strength values exceeding 10 MPa were observed.

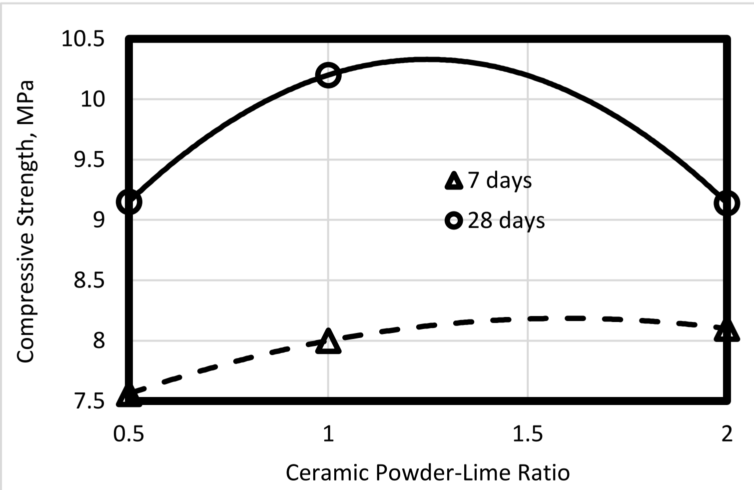

Fig. 5. Compressive strength values of specimens.

4. Conclusions

The following results have been achieved in the study on the evaluation of ceramic wastes.

- In the 7-day samples, with the increase of ceramic powder in the mixture, the unit weights decreased by 2%, ultrasonic pulse velocities increased by 15%, dynamic elasticity modules increased by 30%, compressive strength increased by 7% and there was no significant change in bending strength.
- In the 28-day samples, when the ceramic powder-lime ratio increased from 0.5 to 1, the unit weights increased by 2%, ultrasonic pulse velocities increased by 4%, dynamic elasticity modules increased by 6%, bending strength by 9%, compressive strength by 11%. The physical and mechanical properties of the

specimens were either unaltered or negatively affected when the ceramic powder-lime ratio increased from 1 to 2.

- When the change in the characteristics of age-related specimens is examined, it has been observed that the unit weights, ultrasonic pulse velocities, dynamic modulus of elasticity, bending and compressive strength of specimens have increased over time. Especially the increase in bending strength has reached up to twice the strength of early age.

The study showed that ceramic wastes can be used in the production of Khorasan mortar. Especially the ceramic powder-lime ratio mixtures can be suggested as 1. The compressive strength, which is characteristic for brittle materials, has passed 10 MPa for the ceramic powder-lime ratio 1. It should be kept in mind that the effect of ceramic wastes on the durability of Khorasan mortar should also be determined before being evaluated in the production of Khorasan mortar.

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