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Full Length Research Paper

A research on Karamursel region volcanic tuff as a pozzolanic additive in repair mortars used for historical buildings

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In this research, the chemical properties and pozzolanic activity of Karamursel-Kaytazdere volcanic tuffs were studied. The main aim of this study is to reproduce traditional lime based mortars with local materials for the restoration of historical buildings. With this goal in mind, first of all pozzolana which can be used in repair mortar was researched and then mortars that have similar properties with original mortar were produced in the laboratory by using this pozzolana material. Together with the physical and mechanical properties of the mortars produced in the laboratory were determined with experimental studies. According to the evaluation of the test results of the physical and mechanical properties of the repair mortars, it was seen that the repair mortar samples were compatible with the original samples. It can be concluded that the pozzolanic activity of the volcanic tuff quarried from Karamursel region was found satisfactory.

Key words: Volcanic tuffs, pozzolana, experimental methods, repair mortars, historical buildings.

INTRODUCTION

The volcanic tuff in the region of Karamursel-Kaytazdere has exhibited a high pozzolanic activity when mixed with slaked lime. Hydraulic mortars with slaked lime + natural and artificial pozzolanas had been used in traditional construction techniques which were employed in monumental buildings of Seljuk, Byzantine and Ottoman Eras (Figure 1). The basic principle for designing mortars for architectural conservation can be summarized as matching the physical and mechanical properties of the original mortars and those of the repair mortars. Since Portland cement and white cement are increasing the portion of the micro porosity in the binding medium and the hybrid mortars is not setting with the silicate forming chemical reactions, the mechanical properties are generally inferior to those of the lime + pozzolana mortars (Ozgunler and Ozgunler, 2010).

Consecutively the usage of the lime + cement mortars in conservation is discussable. Instead repair mortars with lime + pozzolana binders should be substituted (Güleç et al., 2003). The experimental studies, which were conducted for the production of traditional mortars with local materials in order to use in the restoration of the ancient structures by evaluating the result of experimental studies performed on original mortar samples were explained in this study.

MATERIALS AND METHODS

The experimental studies were conducted to research pozzolana material that can be used to obtain hydraulic mortar initially. These were ignition loss, chemical analysis with XRF method, XRD and pozzolanic activity tests in line with TS 25 standard (1975). Pilot castings were performed for the production of repair mortar using pozzolana. In order to determine the physical, mechanical properties; tests were performed on the produced repair mortar samples. On repair mortar samples, analyses for water absorption, density, specific gravity, porosity were performed to determine physical properties; analyses for compressive and tensile strength were performed to determine mechanical properties in compliance with TS 699 (1976-2009) and related EN standards.

RESULTS

Firstly, the results of pozzolanic activity tests and

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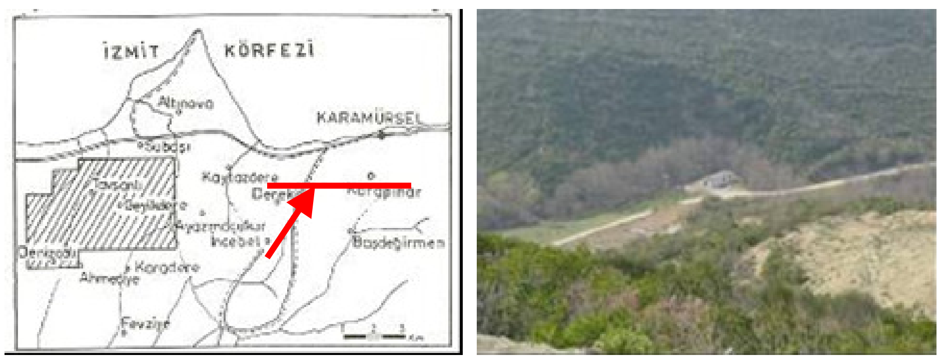
(a) (b) (c)

Figure 1. a)Tekfur Palace (Early Byzantine Period), b) Land Walls of Istanbul (Byzantine and Ottoman Period), c) Ahi Celebi Mosque (Ottoman Period).



(a) (b)

Figure 2. a) The map of Karamursel Region, (Uz et.al., 1995), b) The stone quarries in Kaytazdere, Karamürsel.

Figure 3. The photographs of the natural pozzolana sources in Kaytazdere.

chemical analyses were given, and after determined the properties of pozzolanic material, the test results of repair mortars produced in the laboratory conditions were given consecutively. The results are given briefly in the parts shown in the following.

The results of the research on pozzolana quarries

Turkey is very rich in volcanic tuff type of stones which are natural pozzolans. Using these natural pozzolans with large reserves in lime mortars are seem to be beneficial both in the sense of using traditional material and improving Turkish economy, (Gurdal and Acun, 2006). For this purpose, pozzolanic activity tests were conducted on some of the tuff samples taken from Yalova-Karamursel region which is located near Istanbul and rich in historical tuff mines (Figures 2 and 3). Especially the results of the light colored, acidic tuff sample taken from the tuff mine located in the Kaytaztere town were satisfying. As a result of the researches conducted in this region, various scientific publications

Table 1. The results of chemical analysis pozzolanic material.

Sample	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	TiO_2 %	CaO %	MgO %	Na_2O %	K_2O %	MnO %	P_2O_5 %	K.K. %	Total %
BT*	61.234	16.762	3.425	0.560	5.972	1.93	3.161	1.082	-	-	6.510	100.000

(*)BT: Pozzolana sample code. K.K=Ignition loss ratio.

Table 2. The results of ignition loss of the pozzolanic material.

Sample	Ignition loss at 500°C, %	Ignition loss at 1000°C,%
BT	2.69	3.76

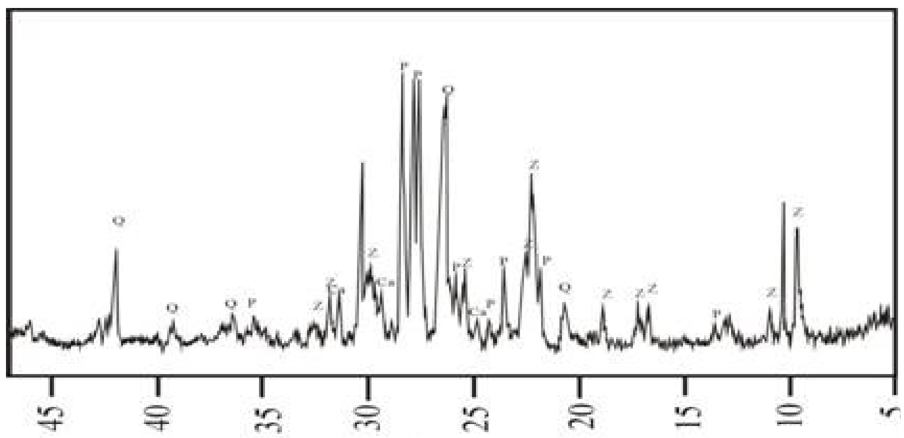


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Figure 4. The XRD graphic of the pozzolanic material.

state that they have pozzolanic activity since these tuffs include large amounts of heulandite-clinoptilolite type of zeolithes (Esenli, 1993).

The results of the chemical analyses of the pozzolanic material

The chemical analysis with XRF method, ignition loss and X-ray analysis were conducted on these pozzolana samples. The results are shown in the following (Tables 1, 2 and Figure 4). These results are evaluated according to TS 25 Standard which shows the experiments done for the determination of pozzolanic activity. Pozzolanic material must provide these chemical characteristics according to TS 25;

$SiO_2 + Al_2O_3 + Fe_2O_3$ = 70% at least.
MgO = must be 5% at most.
SO_3 = must be 3.0% at most.

The chemical characteristic of the Kaytazdere pozzolana as seen the table below;

$SiO_2 + Al_2O_3 + Fe_2O_3$ = 81.42 %
MgO =1.3 %
SO_3 = 0 was found

According to TS 25, ignition loss must be 5% at most. As seen in Table 2, in this pozzolana this value was found as 3.7%. P: Plagioclase, Q: Quartz, Z: Zeolith, Ca: Calcite. P≥Q>Z>Ca.

The results of pozzolanic activity tests

The pozzolanic activity tests contributed to the determination of the pozzolanic properties of the volcanic tuff which was used (Kocu,1997) and (Akgül, 2006). They were conducted in compliance with TS 25. Lime used in the experiments was taken from La Farge Company as unslaked and it was slaked in the laboratory and mixing amounts were determined by calculating water amount. The mixtures were casted in steel moulds. Moulds were rested in a polyethylene bag for one day at the room temperature. Then, the moulds were placed and kept in the oven at 55°C for 6 days for the curing programme. After six days, the samples were taken off from the moulds and left at the room temperature for cooling. After

Table 3. The results of compressive and tensile strength tests of the mortars produced with pozzolana.

Sample No	Dimensions (mm)	Tensile load (N)	Tensile strengths (MPa)	Comp. load 1 (N)	Comp. load 2 (N)	Comp. strengths (MPa)
Sample 1	40/40/160	1100	2.53	20000	21000	12.52
Sample 2	40/40/160	1150	2.64	22000	22000	13.4
Sample 3	40/40/160	1300	2.98	22000	22000	13.4

(a) (b)

Figure 5. The mortar samples which were produced in laboratory conditions (TS 25).

Figure 6. The Khorasan mortar samples which were produced in laboratory conditions.

cooling process, tensile and compression tests were performed. The results are shown in the following, Table 3, Figure 5.

The specific gravity of pozzolana was found as 2.50 g/cm^3 in average.

Pozzolana was used by sieving through 125 µm sieves.

The proportions according to TS25:

Slaked lime = 150 g. (without water)

$$\text{Pozzolana} = 2.150\,.\,\frac{\text{Specific gravity of pozzolana}}{\text{Specific gravity of lime}}$$

Standard Sand = 1350 g.

Water = 0.5 (150 + Pozzolana)

According to TS 25, The compressive strength must be at least 4 MPa for the samples after 7 days of curing time and the tensile strengths must be at least 1 MPa. As the results were above the minimum values. These results indicated that the volcanic tuff which was used as a pozzolanic additive, was very active for silicate forming reactions. The results were given in Table 3.

The production of repair mortar in laboratory conditions

After finding the pozzolanic activity values of the material taken from Kaytazdere appropriate, their behavior in microstructure of traditional lime based mortars were

Figure 6. The Khorasan mortar samples which were produced in laboratory conditions.

Table 4. The mechanical properties of the repair mortar samples produced according to the mixture ratios of Khorasan mortar at the end of 1 week (*).

Sample No	Dimensions (mm)	Tensile load (N)	Tensile strengths (MPa)	Comp. load on 1. Piece (N)	Comp. load on 2. Piece (N)	Average comp. strengths (MPa)
1RM-1	40/40/160	1400	3.1	18000	18000	10.5
1RM-2	40/40/160	1300	2.9	17000	17000	10.0
1RM-3	40/40/160	1150	2.6	17000	17000	10.0

(*) RM: Repair mortar sample code. (*) Results of the tensile and compression strength tests conducted after keeping them in partially moist environment at 60°C for one week. Average Tensile Strength = 2.9 N/mm^2 Average Compression Strength = 10 MPa

Table 5. Average mechanical properties of the repair mortar samples produced according to the mixture ratios of Khorasan mortar, after keeping them in water for 1 month(*).

Sample	Dimensions (mm)	Tensile load (N)	Tensile strengths (MPa)	Comp. load on 1. Piece (N)	Comp. load on 2. Piece (N)	Average comp. Strengths (MPa)
RM-1	40/40/160	800	1.8	22000	22000	13.75

researched. In Turkey, “Khorasan mortars” are mostly known as traditional mortars especially Roman, Byzantine and Early Ottoman Buildings. These mortars are also lime based mortars but crushed brick and dust were used as aggregate. For this purpose, mortar samples were prepared with the addition of pozzolana in the amount that will react with lime in line with lime, brick dust and crushed brick ratios of the samples taken from a historical building (Figure 6); after one week long curing process average of 10 MPa (100 kgf/cm^2) compression strength was found (Gürdal et al., 2010).

The samples prepared as 8 mm and smaller sized crushed brick aggregated from the same mixture were kept in a moist environment for 1 month after production. Within this period, it was seen that the mortar did not crack and its strength increased to 14 MPa.

The mechanical properties of the repair mortar

In order to research the mechanical properties of the samples prepared as repair mortar under different curing conditions, tensile and compression tests were conducted and the results of the experiments were compared. The results of these experiments are shown in the following, Tables 4 to 7, and Figure 7. It has been concluded that in the case of using Kaytazdere origin material in mortars prepared with lime by grinding to the thinness specified in the standard (TS 25), it binds by making calcium water silicates and as a result of these reactions it gains sufficient amount of mechanical strength and doesn’t display the week resistance and dissolution with water contact which are generally seen in lime mortars.

Table 6. Average mechanical properties of the repair mortar samples produced according to the mixture ratios of Khorasan mortar, after keeping them in water for 2 month.

Sample	Dimensions (mm)	Tensile load (N)	Tensile strengths(MPa)	Comp. load on 1. Piece (N)	Comp. load on 2. Piece (N)	Average comp. Strengths (MPa)
RM-2	40/40/160	900	2.1	18000	18500	11.75

Table 7. Average mechanical properties of the repair mortar samples produced according to the mixture ratios of Khorasan mortar, after keeping them in water for 3 month.

Sample	Dimensions (mm)	Tensile load (N)	Tensile strengths (MPa)	Comp. load on 1. Piece (N)	Comp. load on 2. Piece (N)	Avarage comp. Strengths (MPa)
RM-3	41/40/150	910	2.13	21000	21000	12.8

Figure 7. The mechanical property test photographs of the repair mortars.

Table 8. The results of physical property tests of the repair mortar produced under laboratory conditions**.**

Sample	Water absorption (by weight, %)	Water absorption (by volume, %)	Density (g/cm^3)	Specific gravity (g/cm^3)	Porosity (%)
RM	29	43.79	1.51	2.55	41

The physical properties of the repair mortar

As a result of the physical property tests conducted on produced repair mortar samples in line with TS 699 standard, the values for water absorption rate, unit volume mass, specific mass and porosity were found. The results are shown in Table 8. Water absorption rates in original khorasan mortars are between ~ 20 to 40% and porosity values are between 38 to 57%. And repair mortar complies with these properties. The properties of repair mortars which were produced by using Karamursel pozzolana generally match the properties of traditional mortars which were used in the Byzantine and Ottoman buildings.

GENERAL EVALUATION AND CONCLUSIONS

Construction technique and materials of the historical buildings are like documents of early period. Besides the structural originality of the building, originality of materials is also very important. The new materials that are going to be used in the repair should be in visual harmony with the original materials and they should display the performance to act together in respect of static strength and strength against atmospheric conditions. In respect of Turkish economy, it should be a goal to use local materials in order to fulfill these requirements.

With this study, hydraulic property was added to slaked lime, which is a typical binder in historical structures, with pozzolanic property of volcanic tuff type of stones obtained naturally without needing the materials produced with today's technology. Repairs made by using traditional mortars produced in this way were reported to be very successful.

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REFERENCES

Akgul E (2006). An evaluation about the volcanic tuffs in *Datca* region as a building material, (in Turkish). Master thesis, I.T.U. Istanbul,Turkey, pp. 46-53.

Esenli F (1993). The geo-chemical changes on asidic tuffs in *Gördes* neogen region by the zeolithization, (in Turkish). Turkey Geol. B., 36: 37-44.

Gurdal E, Acun S (2006). A research about the khorasan mortars used in historical buildings in *Eyup* and suggestions for the restoration activities, (in Turkish). 10th National Eyup Symposium. Istanbul, Turkey.

Güleç A, Acun S, Ersen A, Gurdal E, Kocu N (2003). Evaluation of *Konya* region volcanic tuff as a pozzolanic additive in conservation mortars. Int. Symp. on Industrial Minerals and Building Stones, pp507-516.

Kocu N (1997). A research on the volcanic tuffs in Konya region as a building material. (in Turkish). PhD thesis, Institute of Natural Sciences of I.T.U Istanbul, Turkey. pp. 35-45.

Ozgunler M, Acun Ozgunler S (2010). Research on deterioration of volcanic tuffs used in Ahi Celebi Mosque in Istanbul. J. Restorat. Buildings and Monuments.,16 (2):109-118.

TS 25 (1975). Tras. Standard prepared based on RILEM standard,

TS 699 (1976-2009). Natural stone test methods, Institute of Turkish Standards, Ankara, Turkey.

Uz B, Esenli F, Manav H, Aydos Z (1995). A research on minerals of pyroclastic stones in the region of Karamursel-Yalova, (in Turkish). J. Earth Sci., 27: 136-139.