ESKİŞEHİR TECHNICAL UNIVERSITY JOURNAL OF SCIENCE AND TECHNOLOGY
A- APPLIED SCIENCES AND ENGINEERING

2020, 21(2), pp. 269 - 281, DOI: 10.18038/estubtda.646812

LIGHTWEIGHT NATURAL PUMICE COMPOSITES FOR REHABILITATION OF HISTORICAL BUILDINGS AND LANDSCAPE WORKS

Aylin ÖZODABAŞ [1,*], Cenk KARAKURT [2]

[1] Department of Civil Engineering, Engineering Faculty, Bilecik Şeyh Edebali University, Bilecik, Turkey
[2] Department of Civil Engineering, Engineering Faculty, Bilecik Şeyh Edebali University, Bilecik, Turkey

ABSTRACT

Historical buildings are made of traditional materials such as mud bricks, lime mortars, stone, and wood. Mud brick is not a durable material against water and compression effects. This study aims to increase the usage of natural pumice in both mortar and block production to obtain efficient restoration material in this area. The specimens obtained by using pumice, slaked lime, tile dust, gypsum and expanded clay at certain ratios were cured in both steam and laboratory conditions. The characterization of the raw materials and specimens were carried out by using BET, XRD, SEM analyses. Also, the physical and mechanical properties of the mortar and block specimens were determined with laboratory tests. The test results showed that the highest compressive strength values were obtained from steam cured specimens. It was observed that the water absorption values of the specimens which were steam cured slightly better than the naturally cured specimens.

Keywords: Restoration, Pumice, Brick, Briquette, Expanded clay

1. INTRODUCTION

Depending on the time and environmental factor significant damage was occurring on historic buildings that are rather rich in Turkey [1]. Therefore, the importance of the protection of historical buildings is an increasing fact. One of the important considerations in the restoration of historical buildings is that the material used in the restoration phase is a material close to the original material [2]. Historical buildings are often deteriorated due to various reasons and can be destroyed by the effect of time and harmful environmental conditions [3, 4]. However, some historical buildings have today a very good condition, depending on the good conservation and accurate materials selection for restoration works and specific technology. Historic mortars composition has a basic role in the preservation of cultural heritage. Therefore the knowledge about the materials used, their performance in their environment and materials for conservation purposes is very important [5]. It is also a very complex matter to protect the historic structural members against climate changes [6].

The physical qualities of historical materials lose their properties over time and they cannot fulfill their purpose of use. Therefore refurbishment is becoming one of the most important sectors offer chance the building to be fit for its aim of use [7, 8]. In historical buildings, restoration works have become necessary to provide their life cycle of structural and non-structural members [9].

Most of the buildings that defined as historical heritage was built by masonry techniques [10-13]. Nowadays, more than 60% of social buildings and 90% of cultural heritage buildings are made of masonry [14-19]. Brick and stone masonry have been substantially used for structural aims up to the mid-20th century, because of the increased labor costs, it became less attractive than other more modern materials such as concrete, glass, and steel. Throughout history, traditional bricks, lime mortars and stones have been widely used all over the world for structures [20-21]. It is possible to say that the addition of brick and tile dust or brick fragments improves the mechanical properties of lime mortars [22].

*Corresponding Author: aylin.ozodabas@bilecik.edu.tr
Received: 14.11.2019 Published:15.06.2020

The use of lime mortars in buildings dates back to antique ages from 12.000 BC [23-26]. Also, lime mortars were used mainly in countries like India, Italy, Greece, and Egypt. Lime mortars were used continuously in construction up until the 21st century [27]. The type of lime, the granulometry of aggregate and the amount of mixing water used in the prepared mortar play an important role in the properties of this material. For instance, large and small pores within the lime mortar absorb the volume expansion during the carbonation [28]. Hydraulic lime mortars are hardened by chemical reaction with water in aqueous and humid environments [29]. While the use of air scale decreases the strength values of the material, the water lime usage is well adapted to the historical structure and the mechanical values are higher [30-31]. The most important disadvantage of lime mortars is the slower setting behavior. Around the 1800s, a significant decrease was observed in the use of lime mortars with the invention of Portland cement. It was a more preferred product due to the high mechanical strength of the cement even though the setting time of the cement was very short. In recent years, since cement has been damaged to historical structures [32], lime mortars have been re-used in restoration works.

Soluble salts in cement form volume expansions in historical buildings and cause flaking and salinization on the surface. When this expansion occurs, the surrounding materials and structural elements will be damaged. [23, 33, and 34]. In the restoration work, original or similar materials should be used to adopt new materials to old materials [35]. If lime mortars usually contain brick dust and brick fragments, these are called Khorasan or Byzantine mortar [36]. The percentage of bricks fragments in the mortar varies between 40-60% [32, 36, and 37]. Clay bricks have better mechanical properties than autoclaved aerated concrete and pumice blocks however poor thermal insulation property is the disadvantage of these bricks. For this reason, the use of clay bricks in buildings is increasingly losing its popularity, which causes the market share of clay brick manufacturers to decrease [38].

Pumice is not only used as a construction material but also in medicine and agriculture areas. Besides this, it can be used for landscaping in the construction of the garden wall or the steps on the ground for visualization. The most important features of pumice stone are lightness and good insulation [39].

Pumice is a porous and light rock type due to volcanic activities [40, 41]. The world's leading producers of pumice are Italy, Greece, Turkey, USA, Germany, Mexico and France [42]. Table 1 shows the major pumice reserves over the world.

Table 1. The world reserves of pumice [3]

Countries	Amount (Million tons)
North America	12.000
Turkey	2.836
Italy	2.000
Australia	500
South America	80

Turkey contains very rich pumice reserves in its geography [43-45]. The pumice is easy to grind in finer particle sizes. But it is difficult to grind in micro-dimensions [46]. Specimens were produced with ground pumice, cement, gypsum, and lime. The physical and mechanical properties of these specimens were better compared to conventional building materials [47]. Briquettes are obtained from a mixture of cement and pumice. The briquette production process is more economical and easier than both aerated concrete and bricks. Nevertheless, the utilization rate is low compared to other materials in the construction industry. Because most of the historical buildings are made of adobe, their resistance against water is very vulnerable [48, 49].

Slaked lime, stream sand, brick dust, and polypropylene fiber materials were used in determining proportions for produce restoration plaster [50]. In this study; pumice based plaster and blocks are used to increase the usage area of the pumice for the restoration and landscape of the historical buildings.

Another aim of this work is to obtain environmentally sensitive products without using cement and to be an alternative to other blocks used in the construction industry.

2. MATERIALS AND METHODS

2.1. Materials

2.1.1. Pumice

Pumice was obtained from the Pumice Research Center Suleyman Demirel University in Isparta-Turkey. Pumice was ground and used in the powder form by sieving it from 0.25 mm sieve.

2.1.2. Expanded clay

In this study, expanded clay was supplied from the Entes Company. The material is ground before using in masonry block production. The ground clay is sieved from 0.25 mm sieve before using the material in the mix design.

2.1.3. Tile dust

The tile used in powder form was obtained from the Turgutlu tile factory. The material is ground in ball mill and screened from 0.25 mm sieve-like other powder ingredients.

2.1.4. Lime and plaster

Slaked lime and plaster were used as a binder in block production. These materials were supplied from SANCIM Cement Factory.

2.2. Method

This study was composed of three experimental steps. In the first step, the fineness of the raw material is determined by BET analyses and mortar mixtures were produced in different ratios by weight of pumice, slaked lime, tile dust, gypsum, and expanded clay respectively as presented in Table 2. Pumice was used fine to gather the pozzolanic activity of this volcanic origin material. It is observed that the unit volume weight of the briquette produced with coarse grain pumice is higher than all samples produced with ground fine pumice. The reason for this is thought to be using only cement as a binder in the briquette, alternatively not using construction materials such as gypsum and lime. The produced mortar bar specimens in dimension with 40x40x160 mm were cured in two different conditions for 28 days. The first curing period was conducted under in-situ conditions of the natural weather conditions. The second curing condition is steam curing inside a special furnace at 100°C. At the end of the curing period, the mortar specimens are immersed in water for 48 hours to determine the water absorption capacity of the specimens. The mechanical properties of the hardened prismatic specimens are determined by compressive strength tests on mortar bar specimens. In the third step of the study mineralogical and microstructure properties of masonry blocks are determined by XRD and SEM analysis in Bilecik Seyh Edebali University central research laboratory.

Table 2. The mix ratios of specimens by weight

Components	Pumice	Slaked lime	Tile Dust	Gypsum	Expanded clay
M1	65	20	10	5	-
M2	55	30	10	5	-
M3	45	40	10	5	-
T1	65	10	20	5	-
T2	55	10	30	5	-
T3	45	10	40	5	-
EC1	60	20	10	5	5
EC2	60	15	10	5	10
EC3	60	10	10	5	15

3. TEST RESULTS

3.1. BET analyses results

The particle size distribution of the powder materials is given in Table 3. As seen from the results the slaked lime is the finest material of the mortar mix content. Tile dust and gypsum have similar specific surface areas. The fineness of the powder material affects the pozzolanic activity of the raw material due to the increased surface area. Fineness also affects the water requirement of the plaster mixes.

Table 3. BET analyses results of the materials

Material	Specific surface area (cm^2/gr)
Gypsum	3.668
Clay	18.681
Slaked lime	22.544
Tile dust	3.304
Pumice	1.008

3.2. Unit Weight

The unit weight of lightweight concretes varies between 1200-2200 kg/m^3 in Norway, a maximum of 1800 kg/m^3 in America and Australia, 800-2000 kg/m^3 in Russia and, 900-2000 kg/m^3 in European standards. In Turkey, it is 800-2000 kg/m^3 according to TS EN 206-1[51]. The unit weights of the produced specimens are given in Figure 1. The briquette specimens have the highest unit weight whereas the aerated concrete has the lowest unit weight. In weather conditions, the unit weights of the cured specimens were close to each other. All specimens had lower unit weights than the traditional bricks and briquettes. In this case, the production of lightweight blocks will save labor costs in the construction site.

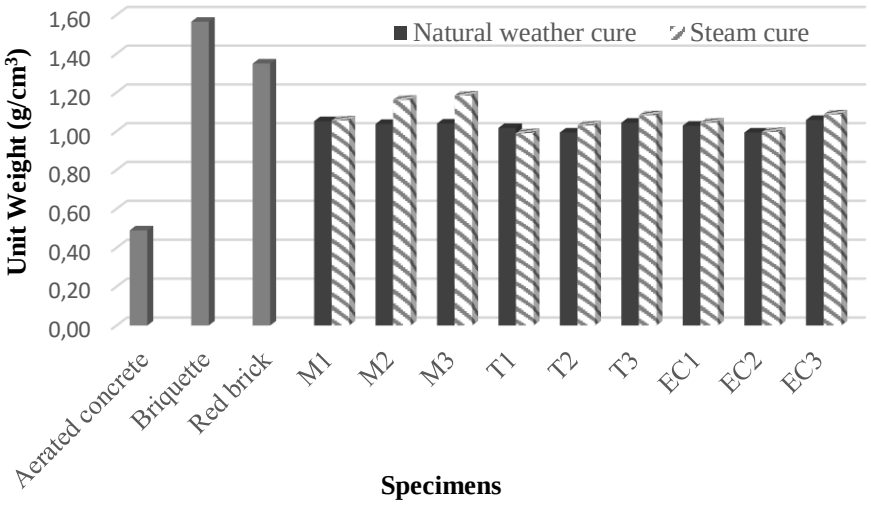

Figure 1. Unit weight weights of specimens' natural weather and steam cure conditions

3.3. Water Absorption Test

Water absorption tests were applied to the specimens which were immersed in water for 48 hours. The results are given in Figure 2. The EC2 specimen was disintegrated during the curing period, thus no data can be obtained from this mixture. The water absorption values of the steam-cured specimens showed better results than the cured specimens in the laboratory conditions. The water absorption values of all specimens were higher than bricks and briquettes and less than aerated concrete. Slightly better water absorption values were obtained from M2 and M3 specimens with steam-curing. In this case, the brick dust and expanded clay used specimens did not show a positive effect on water absorption behavior. However, the graph in Figure 2 shows that the steam-cured effect is a positive effect on water absorption values.

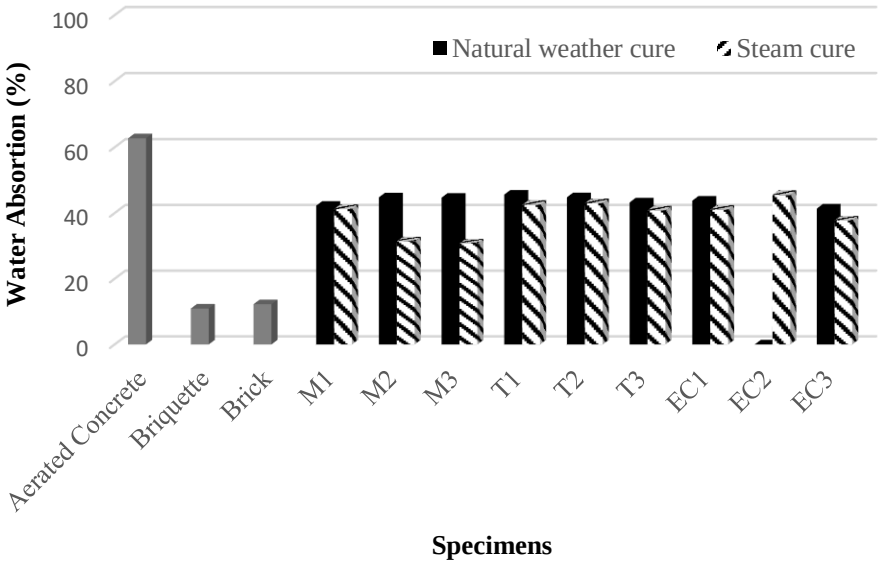

Figure 2. Water absorption results of the specimens

3.4. Strength Test

The compressive strength values of the specimens cured under natural weather and steam cured conditions are presented in Figure 3. The required minimum compressive strength of the masonry units in the European Code is 5 N / mm^2 [21]. The strength test was failed for the EC2 specimen because of the disintegration of this specimen during natural curing. Compressive strength values obtained from all M samples were seen to give better results than other samples. The lowest compressive strength values were obtained from the samples with brick dust content. According to test results, strength values obtained with steam curing conditions showed better results than brick, aerated concrete and briquette.

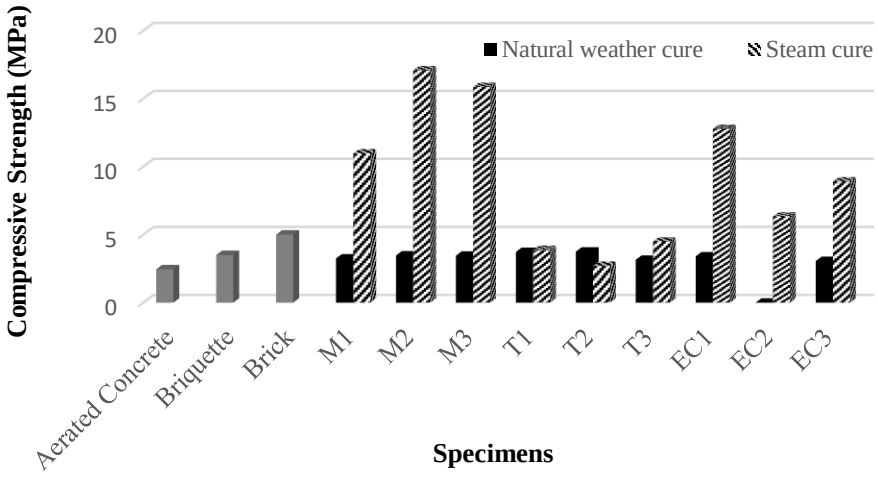

Figure 3. Compressive strength values of the specimens

3.5. Microstructural and Mineralogical Characterization

The microstructure properties and mineralogical characterization of the mortar specimens are determined by SEM and XRD analyses respectively. The SEM images are given in Figs. 4-6. As seen in Fig. 4. The microstructure of pumice used mixtures with constant tile dust ratio, the positive effect of steam curing can be seen clearly. The bonding and CSH distribution of steam-cured M1 specimens showed a more dense and stiff structure. This difference also discloses the mechanical improvement of the steam-cured specimen. There is also ettringite needle formation that occurred inside the pore structure of the M1.

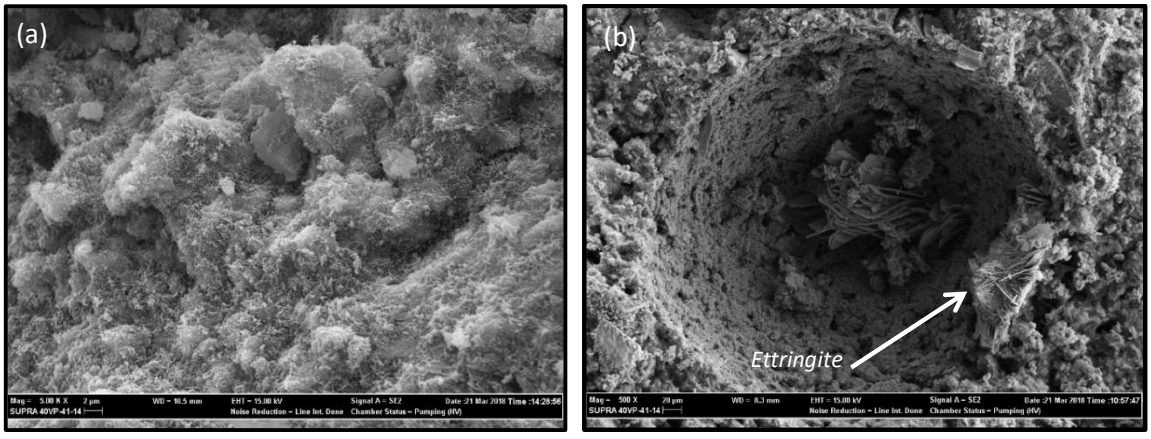

Figure 4. SEM image of M1 specimen: (a) Naturally cured, (b) Steam cured

The microstructure of the T3 specimen is presented in Fig. 5. According to the images, there is no significant internal structure difference between natural or steam cured T3 specimens when compared with the M1 mixture. This behavior can be attributed to the increase of the tile dust amount. The reactivity of the tile dust with lime showed lower performance and this result is also supported by the compressive strength development as given in Figure 3.

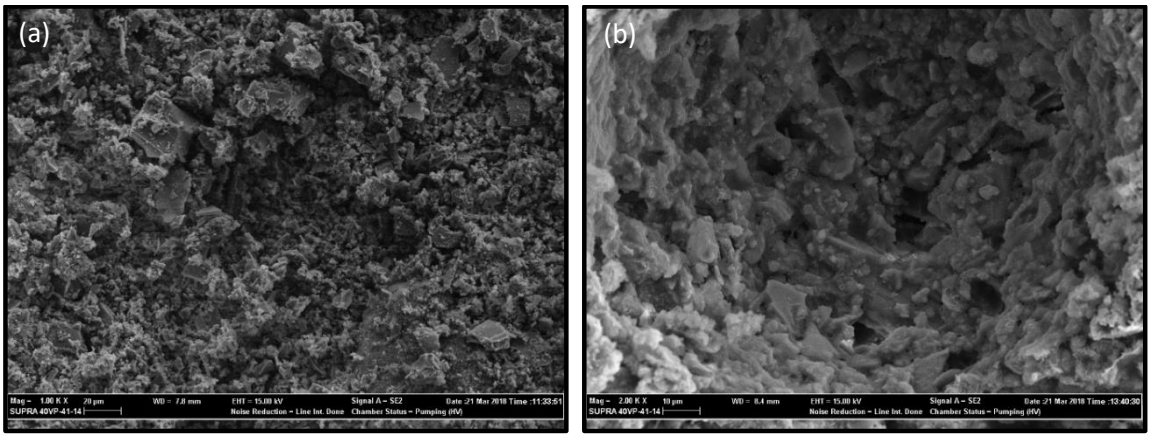

Figure 5. SEM image of T3 specimen: (a) Naturally cured, (b) Steam cured

Another mixture with expanded clay showed similar behavior as an M1 mixture. As seen in Fig. 6. The microstructure of the EC1 specimen cured under steam showed a more dense structure. This structural improvement also complies with the mechanical and physical test results of expanded clay specimens

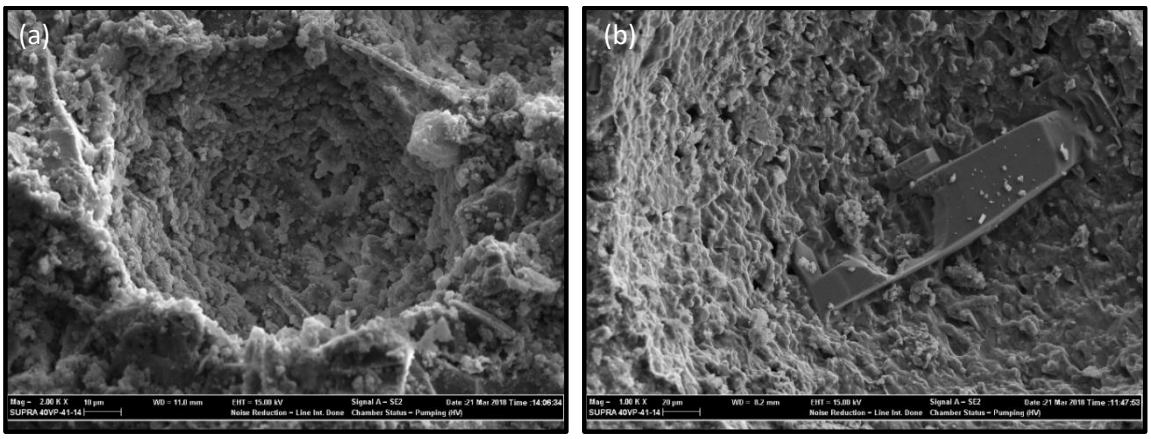

Figure 6. SEM image of EC1 specimen: (a) Naturally cured, (b) Steam cured

XRD patterns of M1, T1, and EC1 specimens are given in Figs. 7-9. The XRD results present that the SiO_2 amount of the mixtures are reduced with the steam curing. This means that the $Ca(OH)_2$ content of the mixture reacted with reactive SiO_2 of the mixtures thus the internal structure formed tobermorite gels to form rigid bonding effect. These results are similar to mechanical and microstructure properties.

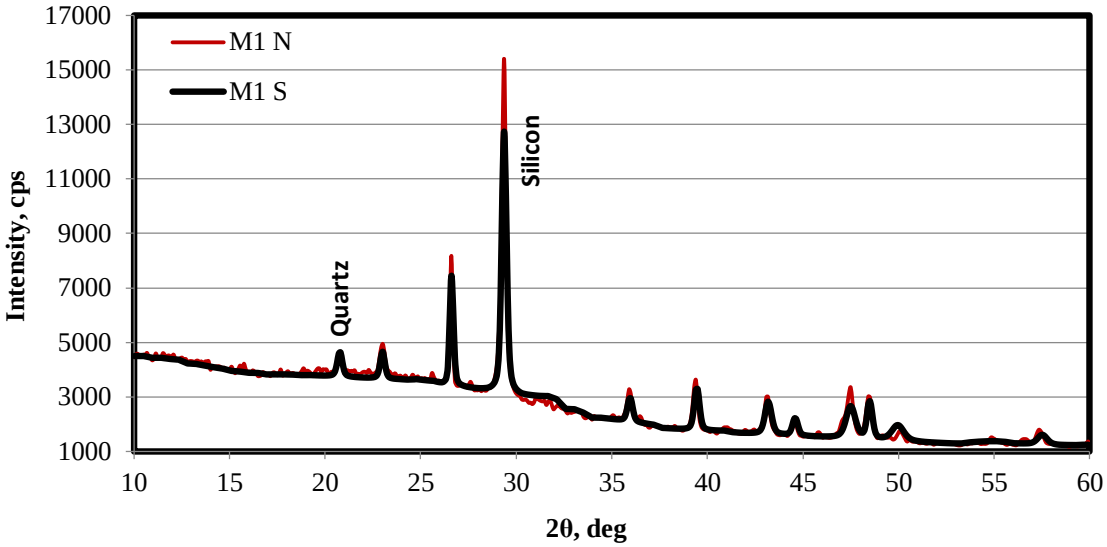

Figure 7. XRD analyses of naturally and steam cured M1 specimen

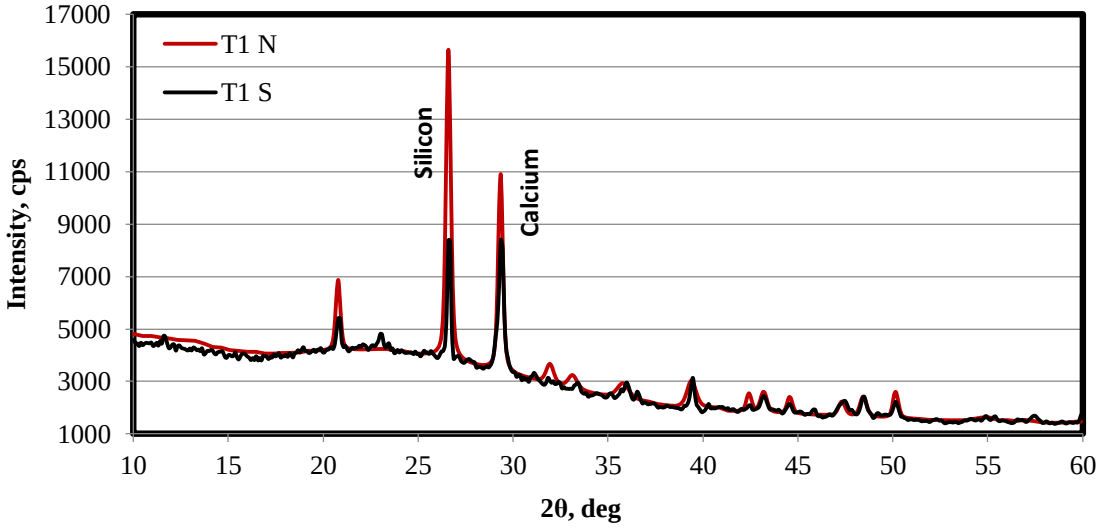

Figure 8. XRD analyses of naturally and steam cured T1 specimen

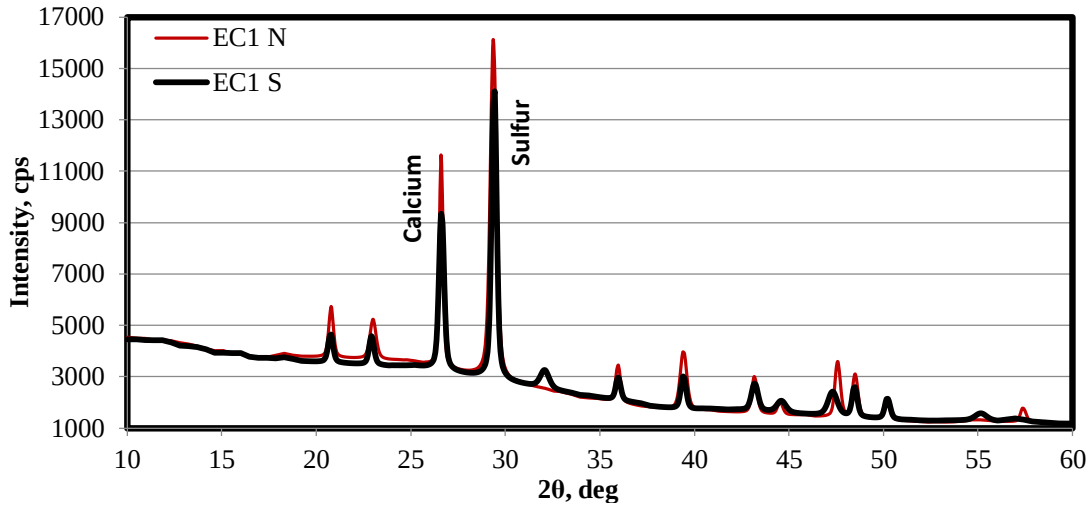

Figure 9. XRD analyses of naturally and steam cured EC1 specimen

4. CONCLUSIONS

The following conclusions can be drawn out from the study.

- The test results showed that all specimens' unit weights are lower than the traditional bricks and briquettes.

- The best water absorption values were obtained from specimens of M2 and M3 which are not tile powder and expanded clay. As can be seen from SEM analysis, it was observed that M samples were denser. Besides, the water absorption performance of all specimens showed better results than briquettes and conventional bricks.

- The lowest compressive strength values were obtained from natural weather cured specimens. The strength values are very close to the strength values aerated concrete and briquettes, while slightly less than traditional bricks. This result can be attributed to the insufficient curing effect on the strength development of the composite.

- The compressive strength values of the M specimens were better than the other specimens. The better pozzolanic activity of pumice influenced the strength behavior of the mortar specimens.

- The highest compressive strength values were obtained from the samples cured by steam. This behavior can be attributed to the increased hydration products under steam curing at an early age.

- Comparing the curing conditions, the compressive strength values of the steam cure specimens gave higher values than natural weather cure specimens. In both curing conditions, lower strength values were obtained from tile dust used specimens.

- To be able to compare with the Khorasan (lime-containing Ottoman mortar) mortar, an alternative study can be done to compare the curing times and curing conditions of both mortars.

ACKNOWLEDGEMENTS

Laboratory works of this research have been financially supported by Bilecik Seyh Edebali University.

REFERENCES

[1] İpekoğlu B, Böke H, Hamamcıoğlu M, Akkurt S. Tarihi yapılarda malzeme bozulmasının sınıflandırılması ve sorunların saptanmasına yönelik bir yöntem araştırılması. Tübitak Proje, 101I035, Ankara, Turkey, 2003.

[2] Erdoğdu Ş, Nas M, Nayır S. Improvement of Mechanical Properties of Lime Mortars Containing Fly Ash and Polypropylene Fibers by Adding Cement, 6th International Symposium on Conservation and Strengthening of Historical Buildings, 2017; 247–256.

[3] Koçak A. Linear and Non-Linear Analysis of Historical Masonry Structures Under Static and Dynamic Loads Example of Small Hagia Sophia Mosque, Yıldız Technical University, Istanbul, Turkey, 1999.

[4] Aslan A. Earhquake Performance Evaluation of Suleymaniye Mosque Depending on Local Soil Conditions, Yıldiz Technical University, Istanbul, Turkey, 2016.

[5] Borges C, Silva AS and Veiga R. Durability of ancient lime mortars in humid environment, Constr Build Mate, 2014; 66:606–620.

[6] Mosoarca M, Keller AI, Petrus C and Racolta A. Failure analysis of historical buildings due to climate change, Eng Fail Anal, 2017; 82:666–680.

[7] Aksah H, Nawawi A.H, Hashim A.E, Dewiyana E. Assessing Score of Applicability and Importance on Functional Performance Criteria for Historical Building, Procedia - Soc Behav Sci, 2016; 222:65–74.

[8] Ahunbay Z, Tarihi Çevre Koruma ve Restorasyon. İstanbul: Yapı Endüstri Merkezi, 2004.

[9] Bozkurt T.S, Sayin B, Akcay C, Yildizlar B, N. Karacay. Restoration of the historical masonry structures based on laboratory experiments, J. Build Eng, 2016; 7:343–360.

[10] Hakan A. Determination of Safety of Historical Masonry Structures by Analytical and Experimental Methods, Istanbul Technical University, Istanbul, Turkey, 2008.

[11] Teomete E. Finite Element Modeling of Historical Masonry Structures; Case Study: Urla Kamanli Mosque, Izmir Technology University, Izmir, Turkey, 2004.

[12] Özen G. Ö. Comparison of Elastic and Inelastic Behavior of Historic Masonry Structures At The Low Load Levels, Middle East Technical University, Ankara, Turkey, 2006.

[13] Yılmaz P. Earthquake Safety Evaluation of Historical Structures, Sakarya University, Sakarya, Turkey, 2006.

[14] Şen B. Modeling and Analysis of the Historical Masonry Structures, Middle East Technical University, Ankara, Turkey, 2003.

[15] Ercan E. Determination of Safety of Historical Masonry Structures by Analytical and Experimental Methods, Ege University, Izmir, Turkey, 2010.

[16] Güner Y. Performance Analysis of Existing Historical Masonry Buildings, Ege University, Izmir, Turkey, 2018.

[17] Akdeniz Ö. Nonlinear Dynamic Analysis of Historical Structures Historical, Firat University, Elazıg, Turkey, 2011.

[18] Ural A. Investigating Linear and Nonlinear Behaviors of Masonry Structures, Karadeniz Technical University, Trabzon, Turkey, 2009.

[19] Arıcan Y. Investigation of earthquake behavior of masonry buildings, Suleyman Demirel University, Isparta, Turkey, 2010.

[20] Segura, J, Pelà L, Roca P. Monotonic and cyclic testing of clay brick and lime mortar masonry in compression, Constr Build Mater, 2018; 193:453–466.

[21] Aydin T. Development of lightweight ceramic construction materials based on fly ash, J Aust Ceram Soc, 2017; 53:109–115.

[22] Navrátilová E, Rovnaníková P. Pozzolanic properties of brick powders and their effect on the properties of modified lime mortars, Constr Build Mater, 2016; 120:530–539.

[23] Ventol L, Vendrell M, Giraldez P, Merino L. Traditional organic additives improve lime mortars: New old materials for restoration and building natural stone fabrics, Constr Build Mater, 2011; 8:3313–3318.

[24] Pavlik V, Uzakova M. Effect of curing conditions on the properties of lime , lime – metakaolin and lime – zeolite mortars, Constr Build Mater, 2016; 102:14–25.

[25] Lynch G. Lime Mortars for Brickwork : Traditional Practice and Modern Misconceptions — Part One, J Archit Conserv, 2014; 4:7-20.

[26] Ravi R, Rajesh M, Thirumalini S. Mechanical and physical properties of natural additive dispersed lime, J Build Eng, 2018; 15:70–77.

[27] Şeker BŞ. Investigation of Behaviour of Architect Sinan's Mosques Under Static and Dynamic Loads, Karadeniz Technical University, Trabzon, Turkey, 2011.

[28] Ortega EO, García RR, Serrano AG, Molina L. Evolution of mechanical properties in aerial lime mortars of traditional manufacturing , the relationship between putty and powder lime, Constr Build Mater, 2018; 191:575–589.

[29] Falchi L, Müller U, Fontana P, Izzo FC, Zendri E. Influence and effectiveness of water-repellent admixtures on pozzolana – lime mortars for restoration application, Constr Build Mater, 2013; 49:272–280.

[30] Rosso F, Laura A, Lucia V, Cotana F, Ferrero M. Smart cool mortar for passive cooling of historical and existing buildings: experimental analysis and dynamic simulation, Energy Procedia, 2017; 134:536–544.

[31] Gulbe L, Vitina I, Setina J. The influence of cement on properties of lime mortars, Procedia Eng, 2017; 172:325–332.

[32] Ersen A. Consolidation of Oolitic Limestone in Monuments, Studies in Ancient Structures Proceedings of the International Conference, Yildiz Technical University, İstanbul, Turkey, 1997; 265-274.

[33] Torres I. New technique for treating rising damp in historical buildings: Wall base ventilation, J Cult Herit, 2018; 31:60–70.

[34] Ergenç D, Fort R. Accelerating carbonation in lime-based mortar in high CO 2 environments, Constr Build Mater, 2018; 188:314–325.

[35] Sala E, Zanotti C, Passoni C, Marini A. Lightweight natural lime composites for rehabilitation of Historical Heritage, Constr Build Mater, 2016; 125:81–93.

[36] Papayanni I. Technology of Mortars and Bricks Used in Ottoman Monuments of Thessaloniki, Studies in Ancient Structures Proceedings of the International Conference, Yildiz Technical University, İstanbul, Turkey, 1997; 245-253.

[37] Ipekoğlu B, Böke H, Çizer Ö. Assessment of material use in relation to climate in historical buildings, Build Environ, 2007, 42:970–978.

[38] Aydin T. Development of porous lightweight clay bricks using a replication method, J Aust Ceram Soc, 2018; 169–175.

[39] Aygun Z, Aygun M. Spectroscopic analysis of Ahlat stone (ignimbrite) and pumice formed by volcanic activity, Spectrochim Acta - Part A Mol Biomol Spectrosc, 2016; 166:73–78.

[40] Bideci A. Investigation of The Properties of Concrete Obtained with Polymer Coated Pumice Aggregates, Trakya University, Edirne, Turkey, 2011.

[41] Kus H, Özkan E, Göcer Ö, Edis. Hot box measurements of pumice aggregate concrete hollow block walls, Constr Build Mater, 2013; 38:837–845.

[42] Gündüz L. Türkiye ve Dünyadaki Pomza Oluşumlarının Malzeme Karakteristiği Analizi, 4.Endüstriyel Hammaddeler Sempozyumu, Izmir, Turkey, 2001.

[43] Yasar E, Atis CD, Kilic A, Gulsen H. Strength properties of lightweight concrete made with basaltic pumice and fly ash, Mater Lett, 2003; 15:2267–2270.

[44] Binici H, Kapur S, Arocena J, Kaplan H. The sulphate resistance of cements containing red brick dust and ground basaltic pumice with sub-microscopic evidence of intra-pore gypsum and ettringite as strengtheners, Cem Concr Compos, 2012; 2:279–287.

[45] Kabay N, Tufekci M, Kizilkanat AB, Oktay D. Properties of concrete with pumice powder and fly ash as cement replacement materials, Constr Build Mater, 2015; 85:1–8.

[46] Cayırlı S. The Investigation and Modelling Behavour of Different Pumices in using Batch Grinding Conditions, Suleyman Demirel University, Isparta, Turkey, 2008.

[47] Sahin S, Orung I, Okuroglu M, Karadutlu Y. Properties of prefabricated building materials produced from ground pumice aggregate and binders, Constr Build Mater, 2008; 5:989–992.

[48] Acun S. A Renewable Material; Adobe and Plaster, Turkey Engineering News, 2003; 71–77.

[49] Özodabaş A. A Research on Improvement of Adobe Material Used in Safranbolu Houses by using Blast Furnace Slag, Sakarya University, Sakarya, Turkey, 2005.

[50] Akcay C, Bozkurt TS, Sayin B, Yildizlar B. Seismic retrofitting of the historical masonry structures using numerical approach, Constr Build Mater, 2016; 113:752–763.

[51] TS EN 206-1, Concrete- Specification, performance, production and conformity, 2004.