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A Research on Sustainability of Traditional Buildings by Re-Using The Local Earthen Materials

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Abstract

It is very important to research renewable energy sources for energy production because of high energy consumption and global warming phenomena. The tendency of using the building materials produced with low energy consumption and respect to environmental conservation has been increasing all over the world. In this context, earthen building materials which are produced by the raw materials taken from the nature and formed by human, can be seen as ecologic and renewable building material. Secondly, earth is a traditional building material, it has been used from past to present with different usage techniques. This material is very important not only for today's ecological demands but also for cultural sustainability. In this study, earthen building materials were researched in order to consider sustainable materials by presenting the advantages and disadvantages. And also, a case study conducted on the earthen building materials of rural area in Bilecik was presented. It was aimed to make a contribution to increase using the earthen building materials in our country with the view of environmental conservation and cultural sustainability. For this purpose, an experimental programme was planned to determine the properties and deterioration reasons of original earthen materials used in traditional buildings and also, to research the re-use possibilities of the originals. As a result of all the experiments, it was seen that the earthen materials can be easily re-used and the performance of the earthen materials can be improved by adding slaked lime %20 and %30 ratios and by obtaining the effective drying conditions.

1. INTRODUCTION

In present, the construction industry is one of the largest and most active sectors throughout all over the world. It is thought that accounts for 30% of carbon dioxide emissions; moreover the global construction industry consumes more raw materials than any other economic activity, which shows a clearly unsustainable industry. In all over the world, the governments emphasize the importance of this unsustainability.

Since the population increases, the construction activites will be continued increasingly. This also means the necessity of building materials will be increased. In this point, it has to be thought the responsibilities against the environment by taking a role in this industry. The affect of building materials on the environment throughout their lifecycle essentially defines the total environmental impact of the buildings in which they are used [1]. So, It must be assumed that the building materials have a major role in construction activities. Therefore, the use of more sustainable construction materials and construction techniques represent a major contribution to the eco-efficiency of the construction industry and thus to a more sustainable development. In the last decade almost one hundred research articles related to this subject have been published in the journals mostly related to earthen building materials.

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In almost every part of Turkey, there exist a large number of traditional buildings with ecological properties which were built at various times in history. The building materials are in general obtained locally and from renewable resources. It is considered that these materials have many more ecological characteristics. They reflect their features on the buildings in which they are used and make them environmental-friendly. This study especially will focus on the usage of earthen materials in traditional buildings. These materials usually can be seen on the traditional building in rural areas. Because of several reasons, earth blocks (called Adobe) was preferred to use. For example, this material is cheap, easily producted and reneawable like these, there are many advantages and some disadvantages as many people knows. The most important problems are durability and the mechanical behaviour against the earthquake impacts. However, there are many studies that shows the scientific results related to improving these properties of earthen material is not impossible.

In this paper, the earthen building materials used in traditional buildings have been observed by a field study conducted in the context of a Scientific Project. Tongurlar village located in Bilecik region was selected as a research area, Figure 1. This village is called as mountain village. There are a few people living today, the others immigrated to the urban areas because of the unhealthy living conditions. This village and traditional buildings are near to unexistence. In order to save the cultural sustainability, the scientists have different professions in MSGSU (Mimar Sinan Fine Arts University) and ITU (Istanbul Technical University) developed a research project supported by the universities' foundations. In the context of this project, the traditional building materials and construction techniques were investigated. Because, the inhabitants prefer to use contemporary materials like concrete briquettes in the buildings instead of using adobe and timber construction. The traditional buildings are timber structured and adobe blocks, earthen mortars and plasters used in walls.

Figure 1. *The general view of Tongurlar village in Bilecik Region*

It was aimed that the determination of characteristics of earthen materials (commonly used) and deterioration reasons then development the material properties to obtain healthy living conditions. The study consists of 3 steps. 1.step; in situ observation, 2. step; investigation of original materials with laboratory tests, 3.step; improving of poor properties by the ecological additives and developing the new earthen materials suggestions for applications.

2. THE GENERAL PROPERTIES OF TRADITIONAL MATERIALS

From past to present, the stones, wood, earth and various plants are used together or alone as building materials. These are called traditional building materials. Especially, in rural areas, usage of the earthen materials are seen commonly for various purposes in the buildings. For example, they were used as a brick (adobe), mortar or plaster in the walls. In most samples, earthen materials were used as a filler for walls and for framed systems in the form of adobe produced with dried earth and vegetable supplement. Like the stone and wood, earthen materials depend on the natural resources and less labor required in order to produce. Using bio-based materials: bio-based building materials are produced from plant fiber waste such as soy, jute, kenaf, wheat, flax, corn, sunflowers, hemp, bamboo, wood, and paper waste. By their very nature, these rapidly renewable materials generate low embodied energy products [2].

The traditional materials are considered as "ecological/green/environmentally-friendly", but the contemporary building materials requires high energy to be producted and most of them are not recyclable [3]. For example, polymers, cement based materials and metals need more energy to be produced. But, nowadays, construction industry show a great effort to minimize the embodied energy of these building materials also. For the sustainable environments, the importance of using sustainable materials must be taken attention. In order to define as a sustainable material some properties must be evaluated like; having recyclable or waste ingredients, being reusable, less embodied energy, not release emissions and particles detrimental to human health (be good for indoor air quality) from cradle to grave, etc…

On assessment of the building materials used in the traditional houses in the rural parts of Bilecik in terms of ecological criteria, we see that they have the below mentioned ecological properties [4].

- The earthen materials require less labor to be produced. They have low embodied energy.
- The raw materials are obtained from natural resources.
- They are easily recyclable or reusable, are produced from waste materials and also cost-effective materials.
- The most important property of these materials is that they are not harmful to humans or the environment. These materials do not emit VOCs (volatile organic compounds) and other harmful chemicals like HCFCs (hydrochlorofluorocarbons) that damage the ozone layer (low-to-no-toxin).

3. THE EXPERIMENTAL WORKS

The experimental works were planned in three steps, and each steps consisted of many substeps defined in the following parts. But, before the experimental works, sampling stage was planned systematically for the chosen traditional buildings. The samples were taken enough amount and dimensions.

3.1. Sampling

The traditional buildings in Tongurlar village located in Bilecik, had timber structures, stone and earthen walls in generally. The buildings were 2 storied. Earthen materials were used as wall brick, mortar and plasters, shown in Figure 2.


a **b** **c**

Figure 2(a-c). *Some traditional house buildings with earthen walls in Tongurlar*

The reasons of using the earthen materials are to provide the earthen materials easily and cheap, also construction techniques are simple, and moreover recycle opportunities in this village. But, this material also requires maintenance frequently, because of its durability properties.

The photographs in the below were taken from a school building, Figure 3. Unfortunately, this building was left alone and never been replied its requirements. But, it has been tried to not to collapse. Even its current situation, it can be still repaired by the earthen materials.


a

b

Figure 3 (a-b). *The damaged school building in the village*

In general, the characteristics of earthen materials depending on the location is varied. The major raw material is clayed earth and straw but some samples have bitumen, gypsum or lime, so the properties may differ according to additives [5,6,7].These additives presents also the local material and construction techniques varieties. So, first of all, properties of the original earthen materials must be determined. In order to determine the properties of the local earthen materials in Tongurlar village, an experimental work was planned.

Before the tests, some representative samples were taken from the chosen buildings. These samples were coded and documented by photographs then put in to plastics bags for the laboratory studies.

Table 1. *The sampling system documentation*

Sample	Location	Code Number	Definition
1	M1	M1-1	Internal plaster
2	M1	M1-2	Internal plaster
3	M1	M1-3	Mortar
4	M1	M1-4	External plaster
5	M1	M1-5	Adobe block
6	M2	M2-1	Adobe block

The experimental works consisted of 3 steps, shown in figure below. The primary tests aimed to assest the general properties of original materials, Figure 4.

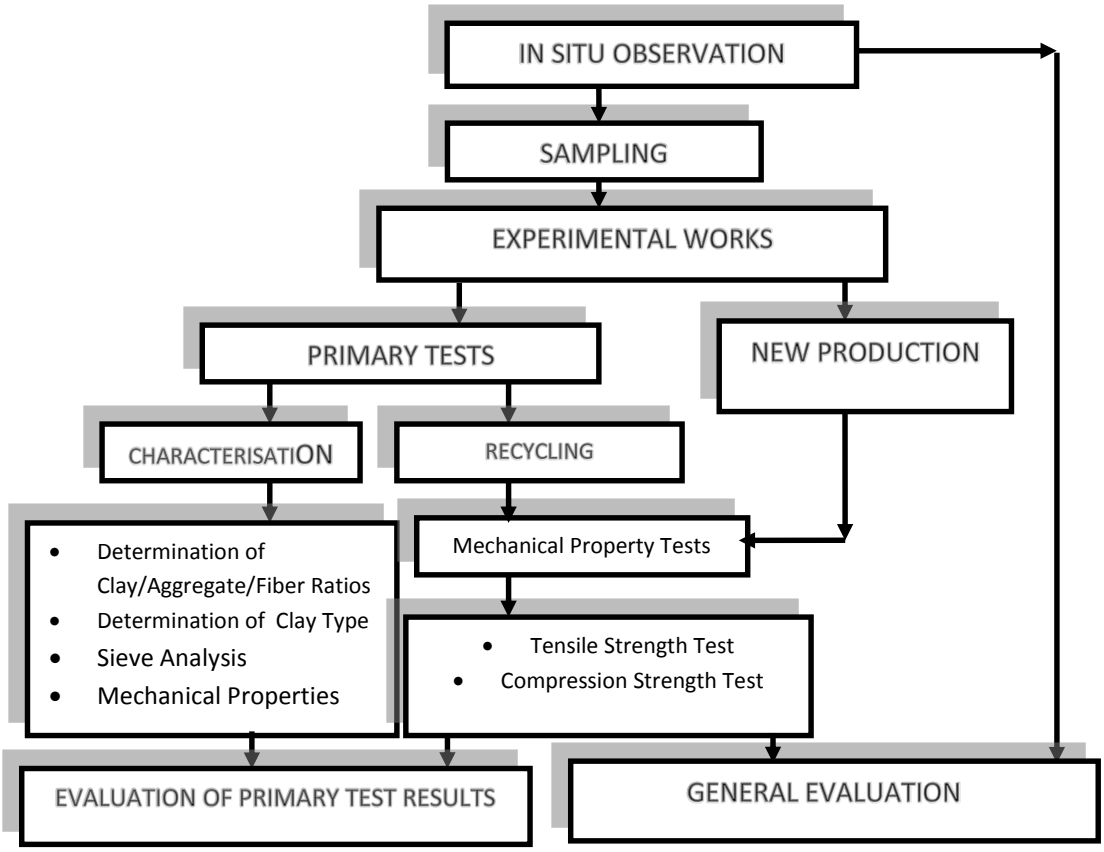

Figure 4. *A flow diagram shows the experimental programme*

3.2. The Results of Primary Tests

Firstly, the characterization tests were conducted in order to define the raw materials type and ratios in the earthen materials taken from Tongurlar village. Then the mechanical property tests were conducted and recycling opportunities were researched. The results are shown in the following parts.

3.2.1. The Characteristics of Earthen Materials

The binder/ aggregate/fiber ratios of earthen materials are determined according to the related standards in laboratory. The results are shown in figure comparatively, Figure 5.

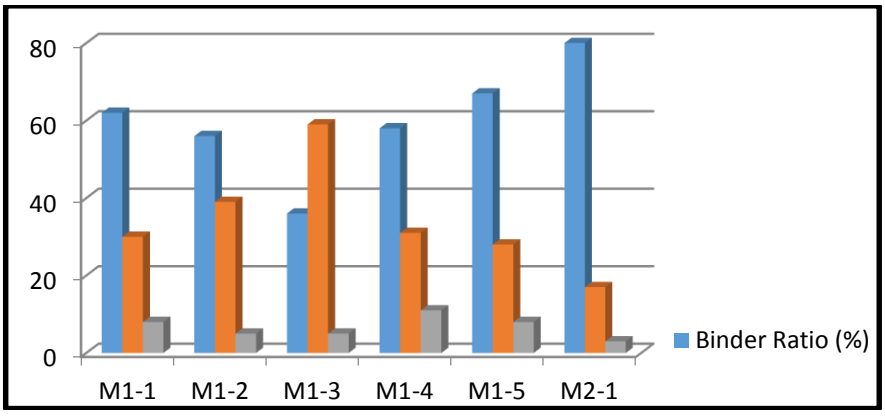

Figure 5. *The results of characterization tests*

The aggregate dimensions in the earthen bricks, mortar and plaster samples are determined by sieve analysis and the results are shown with granulometry graphs in Figure 6.

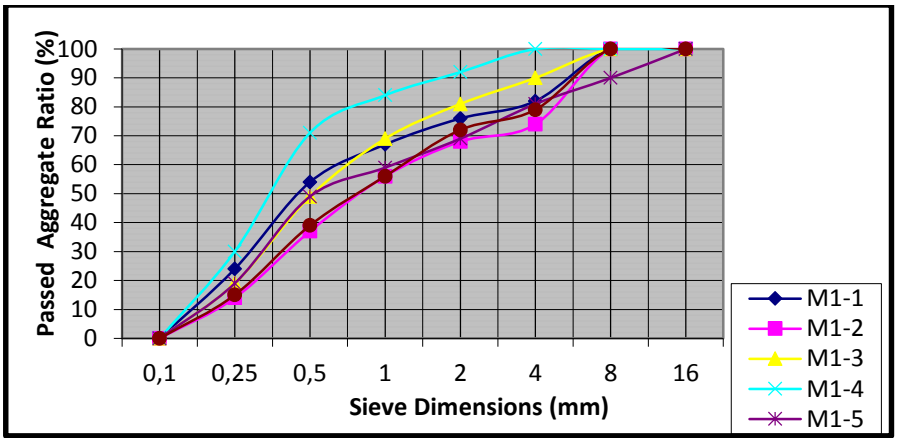

Figure 6. *The aggregate granulometry graphs of the samples*

The Results of Clay Type in Earthen Materials Analysis:

In order to define the clay type in earth, SEM-EDS analysis was conducted in the laboratory. As a result, smectit and caolinite type of clays were determined, Figure 7. These types are accepted as useful to be able to get durable earthen building materials [8,9]. So, the raw material is appropriate in Tongurlar village region.

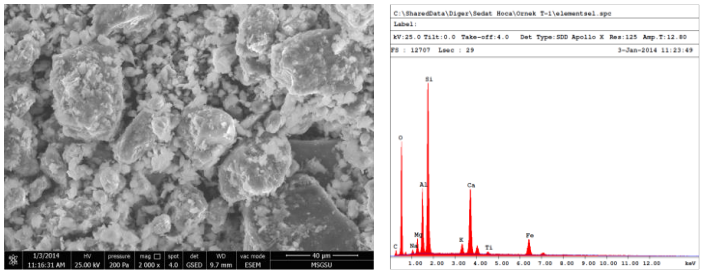

Figure 7. *The results of Sem-EDS Analysis of clay type*

The Results of Mechanical Tests of Earthen Bricks (Adobe):

The mechanical properties of adobe are determined according to the related standards in laboratory. The results are shown in Figure 10 and table 2 comparatively. Adobe dimensions were 9/14/27 cm, Figure 8.

Figure 8. *The mechanical property test photos of Adobe samples*

Table 2. *The average results of mechanical property tests*

Sample	Tensile Strength (MPa)	Compression Strength (MPa)
Adobe, M1	0,2	0,9
Adobe, M2	0,5	1,5

According to the characteristics tests, the original earthen materials were very affected by the atmospheric conditions. There was not found any additive like lime or bitumen which are very useful for increasing the durability. And also, amount of straw and aggregates were not appropriate. So, these earthen materials need to be modified by some ecologic additives in order to have a higher durability.

III.2.2. The Results of Recycling Studies

The broken parts of adobe were mixed by water again. The ideal water ratio was calculated. The 6 samples dimension of 40x40x160 mm were prepared by the steel moulds by press. The three of them were kept in laboratory conditions for 2 weeks, the other three group was kept in 50^{o}C oven for 1 week for drying. After drying, in order to determine the mechanical properties, the tests were conducted related to standards. The average results were shown in Table 3 comparatively with the originals, Figure 9.

Table 3. *The mechanical properties of recycled samples and originals*

Samples	Average Tensile Strength (MPa)	Average Compression Strength (MPa)
Original Block	0,2	1,0
OKN	1,0	2,0
EKN-50	1,3	2,5

OKN: Dried in laboratory / **EKN-50:** Dried in 50^{o}C oven

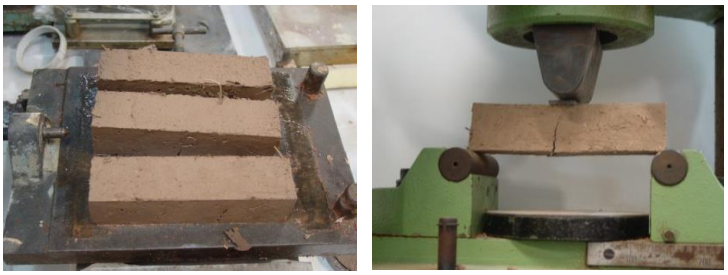

Figure 9. *The photographs that show the mechanical tests of recycled products*

3.3. The New Production Studies of Earthen Materials

In order to have a higher durability of the earthen materials, it was very essential to use additives for the original mixtures. But these additives must have ecological properties. By this purpose, unslaked lime was decided to add in to the mixtures. There was a marble quarry near to Tongurlar village. In the context of this research project, it was planned to use the broken marble pieces (wastes) in order to produce unslaked lime as in the history. The marble wastes were kept in the oven 1100^{o}C, and the lime was obtained by the traditional techniques, as shown in the below, Figure 10.

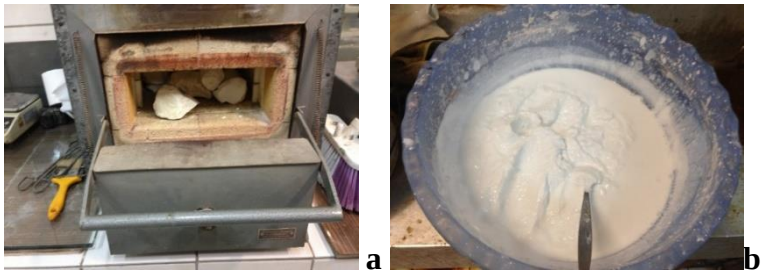

Figure 10. *The photographs that show the lime production processes*

For the new production, mixture trials were made by changing the ratios of lime as 20 % and 30%. The important thing is that the original earthen materials were used again and again, Figure 11.

Figure 11. *The photographs that show the lime production processes*

3.3.1. The Mechanical Test Results of Modified Earthen Blocks

As the mechanical tests, compression and tensile strength tests were conducted on two groups of lime added earthen blocks according to the ASTM and EN standards shown in the below, Figure 12, Tables 4-5.

Figure 12. *The photographs that show the mechanical tests of modified earthen products*

Table 4. *The mechanical properties of modified earthen blocks with different lime ratios*

Sample No	a (mm)	b (mm)	l (mm)	Dried Weight (g)	Flexural Load P (N)	Flexural Strength (MPa)	1.Part Compression Load (N)	2.Part Compression Load (N)	Compression Strength (MPa)
%20-1	38,5	38,1	150	318,3	400	1,1	5000	5000	3,3
%20-1	37,2	36,8	149,2	307,2	450	1,2	4900	5000	3,2
%20-3	38,2	38,0	149,7	320,8	450	1,2	5000	5000	3,3
Average						**1,2**			**3,3**
%30-1	37,7	38,4	149,6	303,8	400	1,1	5000	5500	3,4
%30-2	38,1	36,9	149,1	305,6	400	1,1	4000	5500	3,3
%30-3	39,0	37,4	151,0	317,4	400	1,1	4000	5500	3,3
Average						**1,1**			**3,3**

According to the results shown in Table 4, adding %20 amount of lime was found appropriate. Because, adding the less material, more efficiency is feasible.

Secondly, curing conditions were researched. Six samples were prepared, each of three samples were dried in 30ºC and 55ºC in oven respectively. After that mechanical tests were repeated again. The results are shown in the below, Table 5.

Table 5. *The of mechanical properties of adobe samples dried in 30ºC ve 55ºC oven*

Sample No	a (mm)	b (mm)	l (mm)	Dried Weight (g)	Flexural Load P (N)	Flexural Strength (MPa)	1.Part Compression Load (N)	2.Part Compression Load (N)	Compression Strength (MPa)
Dried in oven 30ºC									
30/1-1	37,6	36,7	148,3	319,7	350	1,0	4000	4250	3,0
30/1-2	37,2	36,7	149,7	318,7	350	1,0	4000	3500	2,8
30/1-3	38,5	37,7	149,8	326,6	350	1,0	4000	4000	3,0
Average						**1,0**			**3,0**
Dried in oven 55ºC									
55/2-1	37,8	37,9	150	309,6	300	0,8	4000	4250	3,0
55/2-2	38,9	38,8	150,7	316,9	350	1,0	4000	4000	3,0
55/2-3	39,0	38,0	150,0	315,9	350	1,0	4000	4000	3,0
Average						**0,9**			**3,0**

4. THE RESULTS AND SUGGESTIONS

After the all tests, an evaluation of the results are obtained. The clay type of local earth is good enough, and also the aggregate dimensions and ratios are appropriate with the TS 2514 [10,11] which consist the requirements to get ideal earthen brick as adobe. The binder is clay and the aggregates are the sand and graves in the earth. The straws are the fiber additives in the earthen materials here. But, the straw dimensions and ratios are found too much in the samples. The additives must be optimized. These factors are highly effective on the features of earthen materials. Moreover, the moulds type and drying conditions are also important. For example, it is recommended that the earth construction must be done in spring or in the beginning of summer term.

Temperature, water and the other environmental factors are effective on these materials during the production processes and application. According to the scientific studies in the literature, durability of these materials can be improved by adding the lime, gypsum, pozzolana or bitumen, and also fibers [12]. For improving the mechanical properties, less amount (2-4%) of cement can be added too. But, it must be remembered that the additives must be chosen according to the ecologic demands. In the last step of the project in Tongurlar village, some additives will be tried for improving the features of the earthen materials, the results will be presented in further publications.

In all over the world, the studies about earthen materials must be continued increasingly in order to improve the contemporary usage in the modern buildings in urban areas not only for the traditional buildings and rural areas. The production of these materials must be standardized by using the today's technology in the material industry. For the sustainable buildings and healthy future, recyclable, eco-friendly, sustainable earthen materials are recommended as a result of this study.

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REFERENCES

[1] Ngowi, A.B., "Creating Competitive Advantage By Using Environment-Friendly Building Processes", Building and Environment, Vol. 36 No. 3 : 291-298, (2001).

[2] Olgyay, V. and Herdt, J., "The Application of Ecosystems Services Criteria for Green Building Assessment", Solar Energy, Vol. 77 No. 4 : 389-98, (2004).

[3] Torgal, P. F., Jalali, S., "Earth Construction: Lessons From The Past For Future Eco-Efficient Construction", Construction and Building Materials 29 : 512–519, (2012).

[4] Esin, T., Yüksek, İ., "A Study on Ecological Properties of Building Materials Used in Traditional Buildings (in Turkey)", Emerald Insight journal Vol. 26 Iss 5/6 : 229 – 241, (2008).

[5] Kafesçioğlu, R., Gürdal, E., "Çağdaş Yapı Malzemesi, Alker", İTÜ yayınları., s. 40, İstanbul, (1985).

[6] Özgünler, Acun, S., Gürdal, E., "Dünden Bugüne Toprak Yapı Malzemesi: Kerpiç", Restorasyon/Konservasyon Çalışmaları Dergisi, sayı: 9, : 29-48, (2011).

[7] Arpacıoğlu, Ü., "Kırsal Sürdürülebilirlikte Yeni Bir Model: Köyünü Yaşat Projesi" Yapı Dergisi, Sayı 421 : 132-138, İstanbul, (2016).

[8] King, B., "Toprak Mimarisinin Yeniden Doğuşu", Mimarlıkta Malzeme, Yıl:5, Sayı:17, : 62-80, Ekim, İstanbul, (2010).

[9] Arpacıoğlu, Ü., "Geçmişten Günümüze Kerpiç Malzeme Üretim Teknikleri ve Güncel Kullanım Olanakları", 3. Ulusal Yapı Malzemesi Kongresi Bildiri Kitabı: 667-679, İstanbul, (2006).

[10] TS 2514, "Kerpiç Bloklar ve Yapım Kuralları", Türk Standartları Enstitüsü, Ankara, (1977).

[11] TS 2515, "Kerpiç Yapıların Yapım Kuralları", Türk Standartları Enstitüsü, Ankara, (1985).

[12] Kafesçioğlu R., "Çağdaş Toprak Yapılar ve Alker", Uygulayıcının El Kitabı, ders notları,İstanbul, (2016).