# Environmental Corruptions on the Ancient Bricks of Kara Arslan Tomb in the City of Konya, Turkey

Arife Deniz OKTAÇ BEYCAN [1]*

[1]Selçuk Üniversitesi, Mimarlık Fakültesi, Mimarlık Bölümü, Konya, Türkiye

**Abstract**

The environmental corruption on the ancient bricks of the Seljuk Empire Period was investigated in this study. A systematic chemical examination for weathered bricks and crusts was performed on the samples both in-situ and in the laboratory which were obtained from the Kara Arslan Tomb located at the center of Konya City in Turkey. A series of chemical solutions (H2SO4, Na2SO4 and NaCl) was used to represent the basic environmental impacts and determine their weathering rates on the ancient brick samples. In this context, the brick samples were subjected to a test procedure repeated at least 15 times and performed by immersing brick samples in acid and sulphate solutions before having their oven-dried conditions. At the end of the tests, the weight losses of the brick samples were calculated and the strength of each sample was performed by using their weight loss percentages. The freeze-thaw deterioration, chemical salt effects and the flame retardant of each sample were also experimentally analysed.

**Keywords**: Brick, Damage, Weathering, Environmental Effects, Chemical Solution.

# Türkiye-Konya Kenti'ndeki Kara Arslan Türbesi'nin Eski Tuğlalarında Çevresel Bozulmalar

**Öz**

Konya Bölgesi'nde Selçuklu İmparatorluğuna ait eski tuğlalarda çevresel etkenlerden kaynaklanan bozulmalar incelenmiştir. Aşınmış tuğlalar ve tabakalar ile ilgili olarak Konya'nın (Türkiye) merkezinde yer alan Kara Arslan Kemer'inden alınan numuneler üzerinde hem arazide (yerinde) hem de laboratuvarda sistematik bir kimyasal inceleme gerçekleştirilmiştir. Eski tuğla örneklerinin aşınma oranlarını bulmak için çevresel temel ana etkiler olarak bir dizi kimyasal çözelti (H2SO4, Na2SO4 ve NaCl) kullanılmıştır. Deney numuneleri, en az 15 defa tekrarlanan asit ve sülfat çözeltilerine daldırma ve etüvde kurutma işlemlerine maruz bırakılmışlardır. Bu deney döngülerinden sonra tuğla numunelerinin ağırlık kayıpları ölçülmüş, her numunenin sağlamlığı yüzde (%) ağırlık kaybı şeklinde belirlenmiştir. Her numunenin donma-çözülme bozulması, kimyasal tuz etkileri ve ateşe karşı dayanıklılığı deneysel olarak analiz edilmiştir.

**Anahtar Kelimeler** : Tuğla, Bozulma, Aşınma, Çevresel Etkiler, Kimyasal Çözelti

## 1. Introduction

Past to present, people have used many construction techniques developed in the course of time in order to build their houses by using various construction materials existing around their vicinity. If the first residences on the world had been considered, adobe and then brick produced by burning adobe has been the first construction material of humans who specified its shape and dimensions according to technology of that period.

In the past, mud kneaded with straw has been given a hand-made oval shape, dried with sunlight and connected with mud mortar by placing them side by side and one on the top of the other (Hodges, 1970). The archaeological excavation works proved that adobe was used in constructing houses whose faces were coated with thick mud plaster at the Hassuna Housing Area (Llyod, 1954) in the south of Nineveh in Mesopotamia and at the Siyalk Housing Area in Central Iran both of which were in B.C. 5000-4000 period. Zigurrat brick was produced for large-scale buildings by baking adobe in the oven in B.C. 3000 (Llyod, 1954) to obtain a strong and durable construction material against weathering. The dimensions were reduced and standardized for brick production and several shapes of bricks were used for various parts of the constructions (Hodges, 1970).

Stone and brick were used together for the constructions of Byzantine Period; especially in Istanbul and its vicinity an extensive brick usage for building load-carrying walls and roof systems can be observed (Mango, 2006).

The structural use of adobe and brick has been widespread in Middle Asia, Turkistan and Horasan where the resident life of Turks has begun (Yaraloy, 1962). Bare brick tradition has been developed as the structural strongness and the decoration art with its different constructions in Turkistan, Horasan, Gazne and Central Iran during Karahans, Gaznes, Great Seljuks Periods and in Northern Iran during the Zengis Period [6]. Brick has been brought to Anatolia as the traditional construction material of Seljuks and began to be used together with stone in Anatolia as the facing or basic construction material in the XI. Century (Bakırer, 1981).

Konya, a Central Anatolian (Turkey) city, complies with this tradition with its many masjids, mosques, madrasas, tombs and minarets having been built with stone and brick during the Anatolian Seljuks Period (Figure 1). The foundations and the bodies of these monuments have been built with stone, and bricks have been used in the domes and vault sections of their constructions to cover their tops. Despite the backbreaking centuries, today these monuments are still alive and being restored against weathering due to environmental conditions. In this study, the damaged bricks that were pulled out during the restoration works of Konya Kara Arslan Tomb (a monument built in Anatolian Seljuks Period) were experimentally analyzed (Figure 2).

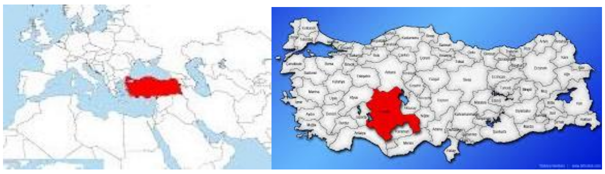

**Figure 1.** Locations: Anatolia (Turkey) in the world and Konya in the Anatolia (Turkey).

Although, no more studies have been performed on the bricks of the Seljuks Period, there are studies carried out for the stone materials. In his book, A.E. Küçükkaya investigated the protection methods and the deterioration causes of the stone materials used in the historical monuments (Küçükkaya 2004).

In the Ph.D. study of T. Esin, the deterioration causes of the stone material used in the historical monuments of Konya and its vicinity were investigated, and the appropriate stone type for the restoration of these monuments was studied (Esin, 1990). In an article written for the region, the negative effects and the results of unfavorable environmental conditions on the stone-built monuments were determined (Çınar et. all 1999). In another article, the effects of salt crystallization of the stone material used in the historical monuments of Konya were measured in the laboratory and the results were discussed (Zedef et.all., 2005). M. Ulusoy analyzed the samples obtained from the stone quarries of the region and used the results of the analyses as the data for the stone-deteriorations observed in the historical monuments (Ulusoy 2007). The physical and mechanical properties of the bricks used in Istanbul Byzantine Architecture was studied by Y. Kahya as a Ph. D. thesis (Kahya 1992).

Although there are several scientific studies on the stone-material used in the historical

*Sorumlu Yazar : A. Deniz OKTAÇ BEYCAN, Yrd.Doç.Dr.
e-mail: deniz@selcuk.edu.tr,

monuments, there exists no specific study related to the bricks of the Anatolian Seljuks Period [14-15]. Brick gets into deformation faster than stone does. On the other hand, although bricks used in the historical monuments have resisted against the destructive effects of the past centuries, they can present a fast deformation tendency due to today's environmental conditions. For the restoration of the Kara Arslan Tomb, the properties of the original worn-out bricks should be determined before replacing them with the new ones. This study has great importance in terms of determining the properties of the brick-material that will be used for restoration works.

## 2. Material and Methods

### 2.1. Field Investigation

Konya is situated at the south end of the Anatolian Plateau in the Central Anatolian Region which was watered with the Meram Brook emerging from the mountainous region of its west and flowing through the east. A hillock named as "Alaeddin Hill" is found at the exact center of Konya in the south of Meram Brook. Many civilizations lived in Konya (with its ancient name "Iconium") throughout the history were settled on and at the vicinity of this hillock. The civilizations lived in Konya in the past can be listed as Hittites, Frigs, Lydians, Persians, Romans, Byzantines, Seljuks, Karamans, Ottomans and the Republic of Turkey. Konya has great importance of being the capital city of Seljuks Empire and the sanjak center of the Ottoman Empire periods. Therefore, today, having many architectural monuments concerning the Seljuks period, Konya is one of the most important Anatolian cities housing the trails of the mankind history.

The residential area named as Çatalhöyük which is located at the 50 km south of Konya is known as the oldest residential area of the world. So much information was obtained about the civilization lived in Çatalhöyük in the Neolitic Period by the help of the archaeological excavations.

The Kara Arslan Tomb, a XIII. Century monument of Seljuks, takes place at the city center of Konya at the eastern part of the Alaeddin Hill (Figure 2- Figure 3). Today, the restoration of this historical building is still continuing whose floor has been buried to the ground surrounded by tall buildings.

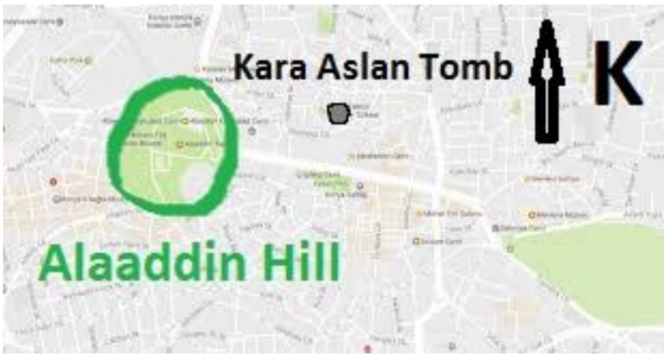


**Figure 2.** The location of Kara Arslan Tomb in Konya

**Figure 3.** Kara Arslan Tomb.

### 2.2. Experimental Study

#### Objective of the Experimental Study

A series of comprehensive tests were carried out to determine the physical characteristics and the performance of the historical bricks currently existing at the historical buildings of Konya Region. Mainly eight types of tests were selected for the project; specific gravity, unit bulk density, water absorption, compressive strength, point load strength, porosity, loss of ignition acid, solution attack, sulfate and salt solution actions and freeze-thaw process by considering the environmental conditions around the bricks.

## 2.3. Materials

Hand-made ancient bricks have been widely used in the historical buildings such as tombs, public baths, caravansaries etc. during the period of Seljuk Empire. Having different raw materials and structural matrix, all these constructions seem to be in various colors. Therefore, they were usually named with their color of appearance. In this research, red-colored ancient bricks were used in all of the experimental studies whose samples were all collected during the restoration works of the Kara Arslan Tomb mainly from its walls and dome, which was located at the center of Konya City, Central Anatolian Region of Turkey (Figure 4–Figure 8). The samples obtained from the restoration area were firstly trimmed by a rock stowing machine to produce 5x5x5 cm and 7x7x7 cm cubic test samples. Some physical properties of the brick samples used in this research are given in Table 1.

Table 1. Physical properties of the test samples.

| Properties Material | Ancient Brick |
|---|---|
| Specific gravity (g/cm3) | 2,75 |
| Bulk Density (kg/m | 1021,85 |
| Water Absorption (%) | 37,00 |
| Porosity (%) | 62,84 |
| Saturated Degree (%) | 58,88 |
| Compressive Strenfgth (N/mm2) | 3,66 |

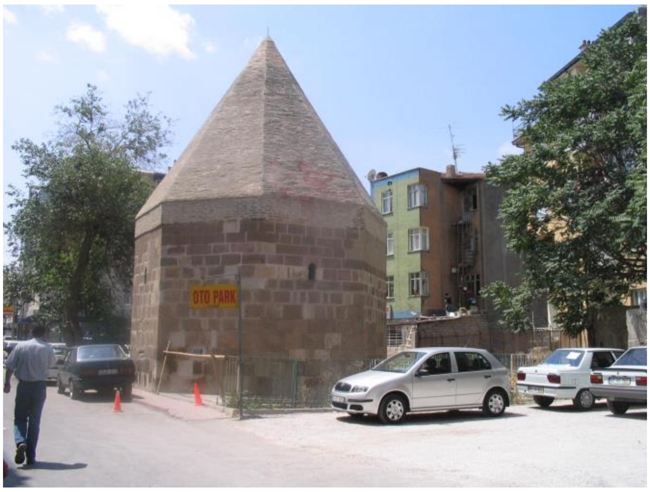


**Figure 4.** The historic building wall surface made by stone and brick material and belonging to Seljuk Empire

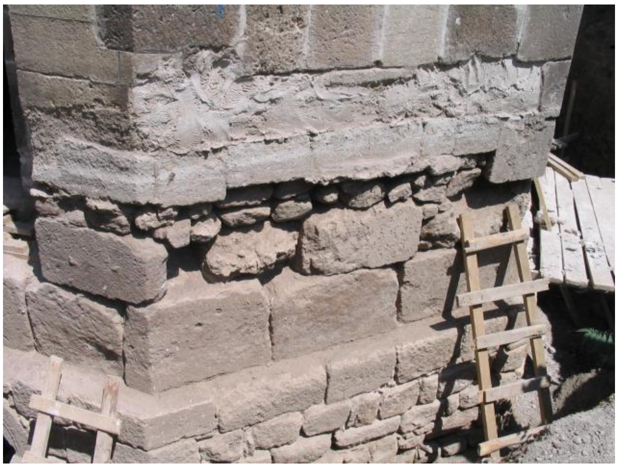

**Figure 5.** The historic building damaged wall surface made by bricks belonging to Seljuk Empire.

**Figure 6.** A wall surface made by bricks belonging to Seljuk Empire

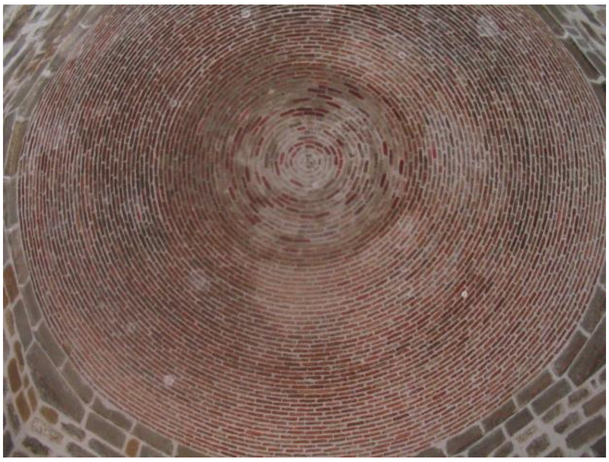

**Figure 7.** The dome sketch of Kara Arslan Tomb belonging to Seljuk Empire.

**Figure 8.** Ancient brick samples collected from Karaarslan Tomb.

## 3. Research and Results

### Freeze-thaw Deterioration

Construction materials produced of soil are mostly friable materials that fail suddenly due to pressure when they are exposed to small amount of deformation. In general, the compressive strength is directly proportional with the physical properties of the brick materials. However, it is affected from some physical properties of the grains like rate of grains, grain sizes, cavities and cavity sizes of grains, micro or macro cracks occurring on the paste at heterogeneous texture. This situation becomes more evident in cold climate conditions [1]. Therefore, the freezing and thawing characteristics of bricks should be analyzed in a series of tests in order to evaluate their durability.

Freezing and thawing tests were performed in accordance with the ASTM C1262-05a [2] standard. This test procedure determines the ability of solid masonry materials to resist against the rapid cycles of freezing and thawing in water. The test procedure involves freezing and thawing specimens while monitoring the mass loss and strength reduction of the specimens during testing. Applying the tests on 70x70x70 mm cubic samples, they were first measured for oven dried condition and their initial compressive strength values were determined as it was done for the chemical resistance tests. The freezing-thawing cycle was performed following the curing and saturation procedure. The cycling procedure was consisted of freezing bricks samples in a deep freezer cabinet at a temperature of -18±4oC and thawing them by submerging in water at 10±2oC temperature.

Frost action is one of the most important physical weathering processes for bricks in cold climates, which occurs due to water freezing inside the joints of the rock and expanding during the repeated freezing process that forces the joints to get enlarged. The freezing-thawing deterioration in rapid condition for all bricks used in this research was analyzed in accordance with the ASTM C1262-05a standard.

The test results of freeze and thaw deterioration for the bricks are given in Table 2. In order to determine the brick quality against the frost action, the compressive strength and the unit weight analyses were basically carried out after the freeze-thaw cycles. This research showed that small amount of weight losses of the bricks occurred after the freeze-thaw processes. While the weight loss value for the bricks varied from 0.83 % to 1.61 % (for bricks with high porosity the weight loss was below the average, 1.34 %), the compressive strength values of the bricks decreased at approximate 42.62% level. In this case, the behavior of the bricks during the freezing-thawing tests depended on some internal factors such as the pores of the matrix and the water content. Furthermore, the bricks presented considerable strength reductions after the freeze-thaw processes.

Table 2. Compressive strength characteristic of the test samples

| Material | Ancient Brick |
|---|---|
| Compressive Strength (Before Freeze-Thaw Cycles) (N/mm2) | 3,66 |
| Compressive Strength (After Freeze-Thaw Cycles) (N/mm2) | 2,10 |
| Strength Loss (%) | 42,62 |

### Resistance against Chemical Attacks

To analyse the damaging effects of the environmental conditions on the performances of the bricks used in the buildings of the Seljuk Empire Period, two test categories were set for the brick samples; (1) chemical resistance tests against acid solution attack; (2) water-soluble salts solution tests. The chemical resistance and the water-soluble salts solution tests were performed on 70x70x70 mm cubic samples in accordance with the ASTM C279 [3] standard. The change in the weight of the specimens immersed in three types of chemical solutions [3% sulphuric acid (H2SO4), 3% sodium chloride (NaCl), 3% sodium sulfate (Na2SO4)] was measured. The tests took 21 days to be completed and the changes in the weights of the brick samples were recorded at the 3rd, 7th, 12th, 18th and 21st days. During the test cycles, the texture, color, appearance and damages of the samples were observed.

**Chemical resistance against acid solution attack**

The damaging effects of a certain chemical solution, namely sulphuric acid (H2SO4), on the characteristics of the sample bricks were analyzed by making a series of experiments during which the chemical concentration of this acid solution was constant with 3% value. The general view of a typical masonry surface exposed to acid solution is given in Table 3. The tests of acid solution attack continued up to the 21st day when the slight weight loss was observed. The weight loss values of the wetting-drying cycles were respectively recorded at 3rd, 6th, 9th, 12th, 15th, 18th and 21st days. The damaging effects of the solutions were considerably related with the wetting-drying cycles at the masonry face. The chemical attack experimentally analyzed for the ancient bricks first starts from the face of the brick and continues through its pores (Figure 9) due to the porous structure of the bricks absorbing the chemical solution with various amounts. The weight loss values of the ancient bricks in 3% chemical solution in a 21 day period are given in Table 3. The maximum weight loss of 44.25% was obtained for the bricks immersed in 3% sulphuric acid solution for 28 days.

Table 3. Weight change of testing samples after interaction of H2SO4 solution.

| Material | | Ancien Brick | |
|---|---|---|---|
| Chemical Concentration | | 1% | 3% |
| Days of Attraction | at 3 days (%) | 39,25 | 40,61 |
| | at 6 days (%) | 41,10 | 41,35 |
| | at 9 days (%) | 41,74 | 42,31 |
| | at 12 days (%) | 41,97 | 42,80 |
| | at 15 days (%) | 41,74 | 43,05 |
| | at 18 days (%) | 41,74 | 43,80 |
| | at 21 days (%) | 41,97 | 44,25 |

**Figure 9.** The efflorescence after bricks interaction with H2SO solution.

**Efflorescence of sulfates on bricks**

Efflorescence is a crystalline deposit event of water-soluble salts on the surface of the masonry materials which presents an unsightly appearance. It is usually in white color, sometimes yellow (usually mineral) due to the salt formed on the masonry bricks as a result of the moisture migrating through the surface of the brick, evaporating and leaving mineral crystals on the brick surface. It is hygroscopic and continues to be accumulated by the attack of more moisture. Only under certain conditions, it is possible for the efflorescence crystals to be formed within the bodies of the units. When efflorescence occurs, cracks and distress problems can occur on the masonry due to the crystallization pressure and the growth of the crystals. There are some certain conditions that should exist simultaneously in order to cause efflorescence. The soluble salts should be present within or in contact with the masonry assembly, or in the facing units, backup, mortar ingredients, trim etc. Water should also be in contact with the salts for a sufficient time period to form the efflorescence (Ghirschman, 1964).

The chemical composition of efflorescence salts is usually alkali, alkaline sulfates, carbonates and chlorides. The most common salts found in efflorescence action are generally the sulfate and carbonate compounds of sodium, potassium, calcium, magnesium and aluminum. Chlorides may also occur as efflorescence. In general, this is because of using calcium chloride as a mortar accelerator, or the contamination event of masonry units or mortar sand by sea water, or the improper use of hydrochloric acids in cleaning solutions (Ghirschman, 1964).

The damaging effects of efflorescence on the ancient bricks were experimentally analyzed by using 3% sodium sulfate solution. The tests of sulfate solution attack were performed for 21 days until the slight weight loss increase was experienced (Figure 10). The weight loss values of the wetting and drying cycles were respectively recorded at 3rd, 6th, 9th, 12th, 15th, 18th and 21st days (Table 4). Bricks have the ability of losing weight and the tests with the sodium sulphate immersion presented that the weight loss of the samples was about 39.87%. In some pores, it was observed that salt crystals occurred at the sides as viscous crust rounds. After drying the brick sample, the soluble salt crystals affecting the capillary action, viscosity, permeability and moisture diffusivity of the material were still remaining in the pores. The formation of the salt crystallization action in the brick samples was recorded in every step of the drying-wetting cycles. In this context, the damaging effects of both sulfate solutions were experienced in terms of weakening the brick samples.

Table 4. Weight change of testing samples after interaction of Na2SO4 solution.

| | Material | Ancient Brick | |
|---|---|---|---|
| | Chemical Concentration | 1% | 3% |
| Days of Attraction | at 3 days (%) | 36,05 | 37,04 |
| | at 6 days (%) | 37,07 | 38,07 |
| | at 9 days (%) | 37,01 | 38,86 |
| | at 12 days (%) | 37,55 | 39,25 |
| | at 15 days | 37,55 | 39,48 |
| | at 18 days | 38,08 | 39,87 |
| | at 21 days | 38,08 | 39,87 |

**Figure 10.** Appearnce of the brick sample after Na2SO4 solution attact.

**Efflorescence of salts on the bricks**

The damaging effects of the bricks due to salt solutions were also determined by making experiments with 3% NaCl salt solution. The samples were subjected to wetting and drying cycles by the capillary action in 3% NaCl salt solution for 21 days (Figure 11). The test results are given in Table 5. As it was experienced before for the sulfate solutions, the efflorescence of each brick sample occurred with crusty white crystals existing at 5-8 mm depths from the surfaces in the 3% NaCl solution. However, this situation may be relatively harmless compared to hidden salt crystallization. At the end, the deterioration was measured by making weight loss evaluation after the solution attack which was found to be 42.35% against the sodium chloride solution effect.

Table 5. Weight change of testing samples after interaction of NaCl solution.

| | Material | Ancient Brick | |
|---|---|---|---|
| | Chemical Concentration | 1% | 3% |
| Days of Attraction | at 3 days (%) | 37,78 | 38,60 |
| | at 6 days (%) | 38,43 | 39,87 |
| | at 9 days (%) | 39,07 | 40,45 |
| | at 12 days (%) | 39,74 | 40,96 |
| | at 15 days | 39,52 | 41,54 |
| | at 18 days | 40,40 | 42,35 |
| | at 21 days | 40,40 | 42,35 |

**Figure 11.** Appearance of the brick sample in relation to NaCl solution.

**Damaging Effects of Flame**

Here, a series of tests were conducted to determine the flame retardant of the brick samples. Therefore, the samples were respectively exposed to a series of heating processes at temperatures 20oC, 100oC, 200oC, 350oC, 500oC, 700oC, 800oC, 850oC, 900oC, 950oC, 1000oC, 1050oC, 1100oC and 1150oC. After each heating process, the samples were weighed to determine their weight loss values in order to analyze the effects of flame on the test specimens (Table 6). As a result, the maximum weight loss of 7.38% was obtained for the brick samples. Figure 12 presents the appearance of the bricks after the heating process was performed with 1150oC temperature.

Table 6. Weight lost of the samples after heating.

| Temparature (T 0C) | Bricks- Samples-Loss Weigth (%) | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | ΔW (%) |
| 20 0C | % 0 | % 0 | % 0 | % 0 | % 0 |
| 100 0C | % 0,91 | % 0,71 | % 1,38 | % 0,69 | % 0,77 |
| 200 0C | % 1,49 | % 1,31 | % 2,04 | %2,04 | %1,66 |
| 350 0C | % 1,86 | % 1,70 | % 2,49 | %1,70 | %1,75 |
| 500 0C | % 2,23 | % 2,04 | % 2,83 | % 2,0 | % 2,09 |
| 700 0C | % 6,97 | % 7,02 | % 8,43 | % 7,31 | % 7,10 |
| 800 0C | % 7,03 | % 7,07 | % 8,49 | % 7,31 | % 7,14 |
| 850 0C | %7,12 | % 7,08 | % 8,53 | % 7,41 | % 7,20 |
| 900 0C | % 7,12 | % 7,11 | % 8,61 | % 7,42 | %7,22 |
| 950 0C | % 7,16 | % 7,15 | % 8,62 | % 7,45 | % 7,25 |
| 1000 0C | % 7,19 | % 7,17 | % 8,67 | % 7,49 | % 7,28 |
| 1050 0C | % 7,23 | % 7,20 | % 8,71 | % 7,51 | % 7,31 |
| 1100 0C | %7,28 | % 7,24 | % 8,83 | % 7,53 | % 7,35 |
| 1150 0C | % 7,31 | % 7,26 | % 8,86 | % 7,58 | % 7,38 |

**Figure 12.** Appearance of brick samples after 1150°C heating.

## 4. Conclusions

In this study, the bricks of the Seljuk Empire Period were used as the load-bearing brick elements. The scope of this experimental study covered the determination of the damaging effects of the acid solution attack, soluble salt action and freeze-thaw actions on the aforementioned brick samples which were tested for acid solution attack and had the weight loss to some degree. The bricks immersed in 3% sulphuric acid solution for 21days had the weight loss of 44.25% that it means the sulphuric acid solutions has high level of damaging effects on the bricks used for masonry.

The weight loss of the brick samples after freeze-thaw cycles occurred considerably very high. However, when the number of freeze-thaw cycles reached to 25 times, the strength reduction of the samples was at negligible level. Even the strength reduction was at the highest level after 180 freeze-thaw cycles, the research proved that all the bricks examined in this study met the required strength values for the load bearing applications.

## References


1)Hodges, H. (1970). *Technology in the ancient world*. Baltimore: Middlesex.

2) Llyod, S. (1954). *Building in brick and stone*. In C.Singer, E.J.Holmyard & A.R.Hall (Eds). A Vol 1. New York: Oxford Press.

3) Ghirschman, R. (1964). *Persia, from the origins to Alexander the great*, London.

4) Mango, C. (2006). *Bizans mimarisi*. çev. Mine Kadiroğlu, Ankara.

5) Yaralov, Y. (1962). 8-12. Yüzyıllarda orta asya'da mimari abideler. *Milletler Arası I. Türk Sanatları Kongresi*. Tebliğler, Ankara.

6) Hattstein, M. & Delius, P. (2007). *İslam sanatı ve mimarisi*, (çev. Nurettin El-Hüseyni), İstanbul : Literatür Yayınları.

7) Bakırer, Ö. (1981). *Selçuklu öncesi ve Selçuklu dönemi Anadolu mimarisinde tuğla kullanımı*. Ankara : ODTÜ Yayınları.

8) Küçükkaya, A.E. (2004). *Taşların bozulma nedenleri ve koruma yöntemleri*. İstanbul.

9) Esin, T. (1990). Konya ve çevresindeki tarihi eserlerde doğal taş malzemenin bozulma nedenleri ve onarımlarda kullanılacak uygun taş seçimi için bir çalışma, *Doktora Tezi*, Selçuk Üniversitesi Fen Bilimleri Enstitüsü, Konya.

10) Çınar, K., Koçu, N., Koç, I. (1999). The negative effects of environment on the historical monuments in Konya (Türkiye). *Fresenius Environmental Bulletin*, 8 (05/06): 236-242.

11) Zedef, V., Kocak K., Doyen A., Ozsen H., Kekec, B. (2005). Effect of salt crystallization on stones of historical building and monuments; Konya, central Turkey. *Building and Environment*, 42: 1453-1457

12) Ulusoy M. (2007). Different ignerous masonory blocks and salt crystal weathering rates in the architecture of historical city of Konya, *Building and Environment*, 42: 3014-3024.

13) Kahya, Y. (1992). İstanbul Bizans mimarisinde kullanılan tuğlanın fiziksel ve mekanik özellikleri. *Doktora Tezi*. İTÜ Fen Bilimleri Enstitüsü, İstanbul.

14) Eskici, B., Akyol, A., Kadioğlu Y. K. (2006). Erzurum Yakutiye Medresesi yapı malzemeleri, bozulmalar ve koruma problemleri. *Ankara Üniversitesi Dil ve Tarih-Coğrafya Fakültesi Dergisi*, 46, 1 (2006) 165-188.

15) Eroğlu M., Akyol A. (2017). Antik yapı malzemesi olarak tuğla ve kiremit: Boğsak adası Bizans yerleşimi örneklemi. *Gazi Üniversitesi Güzel Sanatlar Fakültesi Sanat ve Tasarım Dergisi*, (2017) 20, s. 141-163.