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# Determination of The Physical and Mechanical Properties of the Materials Used in The Northern City Walls of Historical Sinop Castle

Ruya Kilic Demircan<sup>1</sup>, Gokhan Kaplan<sup>2</sup>, Ali Ihsan Unay<sup>3</sup>

<sup>1</sup> Gazi University Technology Faculty Civil Engineering Department, Ankara-Turkey

<sup>2</sup> Kastamonu University, Kastamonu Vocational School, Construction Depart., Turkey

<sup>3</sup> Gazi University Faculty of Architect Department of Architect, Ankara-Turkey

ruyakilic86@gmail.com

**Abstract.** Turkey is a country that has hosted many civilizations due to its geographical location. The artefacts of these civilizations constitute important historical heritages of the country. The preservation, restoration and strengthening of historical artefacts and their transfer to future generations are the responsibilities of every country. Historical Sinop Castle that investigated in this study locates in the Sinop city where takes place northernmost of Turkey. Sinop province is a half island due to its geographical position and it is known that the castle walls were built due to the protection of this city. It is not known exactly when the historic Sinop Castle was built. It is estimated the time period of built could be 8th century B.C based on excavations. It is known that to hosted the Milets, the Cimmerians, the Persians, the Romans, the Byzantines, the Seljuks and the Ottoman Empire. Sinop Castle, which could survive until today, has a length of 880 m in the North, 500 m in the east, 400 m in the south and 273 m in the west, and it defines the old borders of the city. It is observed that northern city walls of castle (Kumkapı Site) have been subjected to natural influences due to the its location and it is in danger of collapse. The purpose of scientific research on materials used in historical buildings; to obtain more information about visual, physical, mechanical and mineralogical properties of materials used in these structures. Using this information, suggestions on material selection to be used in the restoration of structures will be presented. In this study, stone and mortar samples were taken from the northern city walls of castle (Kumkapı Site) under the necessary laws and regulations. It was paid attention for the stone and mortar samples taken from the area at the sea level of the castle were intact. Samples of stone and mortar are masonry samples on the front surface, filler part and back surface of the castle. As physical analyzes on the samples; water absorption rates (bulk/ weight), real density, apparent density, porosity, and pressure resistance tests as mechanical analysis were applied. In accordance with the results obtained, the suitability of the material with the material values used in the literature was emphasized. In addition, it was aimed to suggest restoration proposals that compare the mortar samples taken from the castle walls with the mortar samples of some researchers in the literature.

## 1. Introduction

From the beginning of human history until today, in the history of thousands of years of civilization, the structures created by human beings, either directly or with help of nature, constitute the cultural heritage of today. Turkey is a country that due to its geographical location, many civilizations have



hosted it, and it has countless historical structures from these civilizations. While these constructions can often survive against the weary power of time, nature, humanity, and technology, a significant decrease of strength and durability in these structures is observed. The essential restoration steps should be carried out by specialists without losing its originality of the structure by determining preliminary studies. Determination of the material properties of structural elements correctly is a very important step and many studies have been carried out on this subject in recent years.

Sayın worked on the improvement process of a historical structure used Istanbul University Faculty of Political Sciences. He investigated the historical process of construction and identified the points to take material samples. He determined the characteristic, chemical and mineralogical properties of the mortar, plaster and wood materials which he had taken. He presented application methods for conservation and restoration in the direction of the data that he has found [1]. Aköz and Yüzer defined the properties of the materials without harming the historical structure in scope of the current law, and explained the experiments to be carried out in the field and in the laboratory [2]. Conte et al. worked petrographic analyses coupled with scanning electron microscopy, X-ray powder diffraction, and X-ray fluorescence on mortar samples from the walls of S. Maria di Cerrate church. These methods were selected to maximize the understanding of the S. Maria di Cerrate mortars, ranging in age from the 12th to the 20th century [3]. Papayianni et al. researched on mortar samples (structural, plaster, floor substratum), taken from Roman Odeion of the archaeological site of Dion, and mortars were analyzed, regarding their physico-mechanical, microstructural and chemical properties. The evaluation of test results led to the definition of their structure and consistency, while proposals for repair materials were made. Through the analysis, selection of suitable repair mortars were presented [4]. Chiarelli et al. studied of the mortars from the S. Niccolò archaeological site in Montieri (Tuscany – Italy). the petrographic, mineralogical and chemical characterisation of the samples was obtained by the use of multi-analytical techniques [5]. Papayianni and Stefanidou studied of mortar samples from taken from the remains of ancient Olynthos. They showed that different qualities of mortars were used for different purposes [6].

In this study; the physical and mechanical properties of stone and mortar material samples of Sinop Castle North City Walls were being determined. The data obtained were compared with the literature data. As a next step, SEM analyzes on mortar specimens and petrographic analyzes on stone specimens are aimed.

## 2. History of Sinop Castle

The exact date Sinop Castle was built remains unknown to this date. A number of researchers dated the castle back to the Hittites, however, there is no finding to confirm this suggestion.

One of the most sheltered castles built by the coast of Anatolia, Sinop Castle is most like built after the colonization period. The fact that Sinop witnessed a failed sieged attempt (in 220 BC) well before the date Pharnaces I of Pontus conquered the city in 183 BC supports this suggestion. A failed siege would only be possible if the city was protected by strong city walls [7].

The preminence of the city was increased politically after Sinope became the capital of Kingdom of Pontus, and the castle was further fortified by Mithradates VI of Pontus. In the following centuries, the castle was expanded, maintained and restored in Roman, Byzantium, Seljuk, Anatolian Beyliks and Ottoman periods, respectively, and it survived to this date. The citadel, on the other hand, was an addition to the structure during the Great Seljuk Empire period.

The citadel walls are 18 meters high with a width of 3 meters. On top of the walls were passageways allowing the guards to patrol the citadel covering all the perimeter. The outer walls of Sinop Castle run 880 m to the North, 500 m to the East, 400 m to the South and 273 m to the West. The Northern citadel was built on an area of 16,875 m<sup>2</sup>, while the Southern citadel, also known as the Sinop Castle Prison, was built on an area 9,500 m<sup>2</sup> [8].

Having witnessed a number of Ottoman-Russo wars, defensive walls of the Sinop Castle were damaged severely during the Battle of Sinop (1853). Aerial images of Sinop taken by German aircrafts between 1915 and 1920, i.e. during and after the WWI, showcase the continuity of the castle (Figure

1). In the early years of the Republican era, the Western wall of the outer castle and the Western and Eastern walls of the citadel were demolished to provide access to the city. Today, the city walls remain partially intact, while the citadel survived the centuries almost in its original form. This study is limited with the Northern walls of the castle.



**Figure 1.** 1915-1920 World War 1, picture taken by the German planes

### **3. Identification of Material Properties**

The common purpose of scientific studies focusing on the materials used in historic structures is to obtain data about the visual, physical, mechanical, and mineralogical properties of the materials used in these structures. Then, suggestions are made for the selection of restorative materials to be used in and around historic structures. In this study, mortar and building material samples were collected from the Northern Walls of Sinop Castle (Kumkapı Site in Figure 2) using non-destructive sampling methods as suggested by the regulations and standards in place. These samples were then analyzed for their physical and mechanical properties.

#### **3.1. Northern Walls of Sinop Castle (Kumkapı Site)**

The best locations for sample collection were found as a result of the survey of Sinop Castle. The definitive parameter of the location selection for sample collection was that the samples were collected from intact original stone and mortar material which was not exposed to the deforming effects of the sea water as the castle was built on sea level. The masonry samples were collected from the outer facade, backfill and inner facade of the walls. Masonry samples were collected in accordance with the standards using hammer and chisel.



**Figure 2.** North Baileys of Sinop Castle (Kumkapı Site)



### 3.2. Stone Samples

Stone samples were collected from three different points, namely, the outer facade, the inner facade facing the large bastion and the backfill. The samples were then subjected to physical and mechanical (strength tests) analyses.

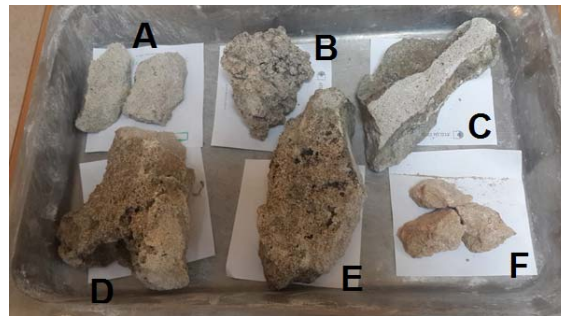
Stone Sample A was collected from the backfill; Stone Sample B was collected from the outer façade; and Stone Sample C was collected from the inner facade of the castle. Stone Sample D, on the other hand, was collected from the outer facade, however, as it was of petrified clay and silt material, it was not possible to collect a borehole sample. The sample was dissolved during the borehole sampling as soon as it was subjected to sea water. Stone Sample E was collected from the backfill. Stone Sample E was of sand, clay and silt material. This sample was also dissolved during the borehole sampling as soon as it was subjected to sea water. The sampling locations, samples and the borehole samples are listed below (Figure 3).



**Figure 3.** Stone Samples

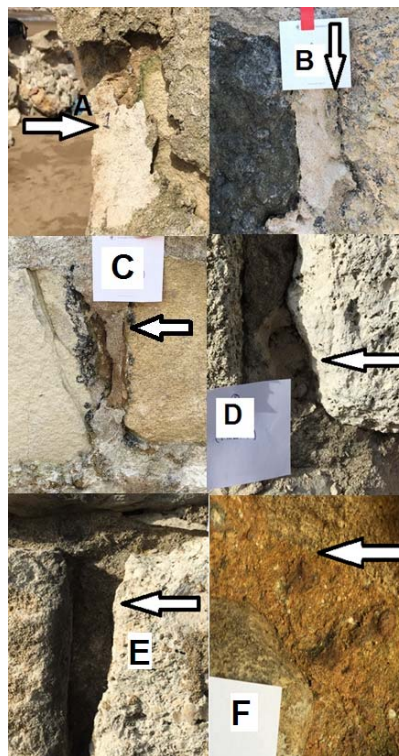
### 3.3. Mortar Samples

Mortar samples were collected from three different points, namely, the outer facade, the inner facade facing the large bastion and the backfill. Sample of mortars were taken in Figure 4. The samples were subjected to physical analyses and data was obtained. As it was not possible to obtain borehole samples, it was impossible to perform mechanical analyses.



**Figure 4.** Samples of Mortars

HA, HB, and HC mortar samples were collected from the outer facade which is exposed to sea water; while HD and HE mortar samples were collected from the inner facade; and HF mortar sample was collected from the backfill. Sampling locations are shown below in Figure 5.



**Figure 5.** Samples of mortars which were received their locations

### 3.4. Physical Analyses

#### 3.4.1. Water absorption ratios by mass and volume

Water absorption tests were performed in order to define the water absorption ratios of the stone and mortar samples by mass and volume [9,10]. The dust available on the sample surface was cleaned using a compressor. After being cleaned, stone and mortar samples were dried in a stove at 60 °C for 48 hours. Being removed from the stove, stone and mortar samples were cooled down in a desiccator and their dry weight was recorded. This was followed by measurements of saturated unit weight and submerged unit weight taken after the samples were kept in water for 48 hours.

#### 3.4.2. *Apparent density*

As the mortar samples were formless, their apparent densities were calculated using water absorption measurements [10,11]. The samples were dried until they reached a constant mass and their apparent densities were calculated using saturated unit weight and submerged unit weight values.

#### 3.4.3. *Real density*

Tests were performed using a pycnometer in order to find the true density of stone and mortar samples. Ground stone and mortar samples were subjected to sieve analysis, separately, using a 120 mesh sieve and the results were recorded. Having filled the pycnometer with water and sealed, and the device was weighed and the measurement was recorded. Then, removing enough water from the pycnometer, mortar sample was put inside the device and it was shaking in order to have a homogeneous fluid and solid distribution. Having filled the pycnometer with water as much as possible, the device was sealed. The device was then stored until the solid material was deposited at the bottom of the water and the water was clear. Pycnometer was then weighed and the measurement was recorded. Using the formula below, volumes of the samples were calculated which in turn was used to calculate the true density of the samples.

#### 3.4.4. *Porosity*

Porosity is the measure of the void spaces in a material, while compactness is a condition of soils with reduced void ratio. Compactness values of the samples were calculated first using apparent density and true density values and in order to calculate the porosity [11,12], and void ratios of the material were calculated using the compactness values found [13].

### 3.5. *Mechanical Analyses*

Mechanical properties of solids include any behaviour shown under the action of external forces. Properties such as load-bearing capacity, durability, etc. of structural materials are among the mechanical properties of those materials. Natural stones, processed earthen materials, etc. used in historic structures are commonly brittle materials which are not capable of plastic deformation due to their nature if they offer low tensile strength and high compressive strength. Such materials are subject to minimal deformation under mechanical strain, however, structural failure comes quite suddenly. Structural defects, nicks, burrs, and micro-cracks result in strain accumulation in brittle materials failing in such manner.

Compressive strength tests were performed in accordance with the provisions of the standard in place [14] in order to find the compressive strength of authentic mortars used in historic structures.

#### 3.5.1. *Compressive Strength*

It is often hard to collect samples of the sizes defined in the test standards governing the mechanical properties of a sample recently extracted from a historic structure. Nevertheless, it would be the best to adopt a holistic approach to the mechanical assessment of masonry structures which are non-homogeneous composite systems. Identification of the mechanical properties of authentic mortars, on the other hand, is necessary in terms of restoration mortar design [15].

Borehole samples were taken from stone and mortar materials in order to determine the compressive stress. Due to unfavourable conditions present at the locations for borehole sampling, samples were not collected on-site. Stone and mortar samples were dislocated and transported to the city of Ankara. Borehole drill bit was custom designed to accommodate the size of the samples (2.75 in diameter).

Although it was possible to obtain borehole samples from stone samples, we were not so lucky with mortar samples. Stone samples obtained in the form of a cylinder were tested in a uniaxial compression test device and the measurements were recorded.

#### 4. Results

##### Physical & Mechanical Analyses:

Test results obtained from the physical analyses of stone and mortar samples are given in the table. 1 below.

As HF Sample dissolved both in water and alcohol, it was not possible to perform these tests on this sample.

**Table 1** Physical Analyses of Stone and Mortars Samples

SAMPLES	Sk (%)	Sh (%)	$\Delta$ (gr/cm <sup>3</sup> )	$\gamma$ (gr/cm <sup>3</sup> )	Porosity(%)
	Water absorption percent by weight	Water absorption percent by volume	Apparent Density	Real Density	
TA	16.33	28.96	1.77	2.59	31.53
TB	12.01	22.02	1.83	2.65	30.79
TC	1.92	4.8	2.5	2.69	7.11
TD	11.51	20.94	1.82	2.66	31.53
TE	3.17	7.38	2.33	2.62	10.92
AVERAGE	8.98	16.82	2.05	2.64	22.37
Standard Deviation	6.19	10.31	0.34	0.04	12.27
HA	19.05	29.36	1.54	2.37	41.89
HB	15.27	25.11	1.64	2.35	30.21
HC	13.91	24.9	1.72	2.66	35.34
HD	15.88	26.19	1.64	2.45	33.06
HE	13.27	23.24	1.75	2.75	36.37
HF	-	-	-	-	-
AVERAGE	15.47	25.76	1.66	2.57	35.37
Standard Deviation	2.25	2.27	0.08	0.18	4.34

Physical properties of stones such as density, porosity and water absorption are correlated with their mass, volume and void ratio/porosity. Density of a stone/rock would be reduced if there are voids in the material structure, which in turn reduces the strength of the rock making it more prone to deformation. Moreover, this effect will be stronger if the voids/pores are saturated with water.

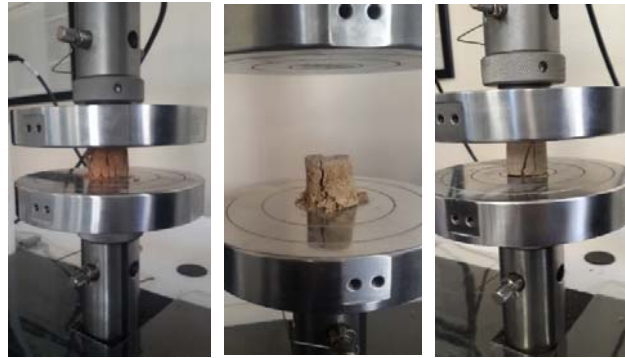
Borehole samples were taken from stone materials in order to determine the compressive stress. A custom borehole drill bit was obtained in accordance with the size of stone samples. Stone samples obtained were tested using a uniaxial compression test device with three repetitions and the mean values were found (Fig.6-7). The following diagrams illustrate the compressive strength findings.

As shown in the table. 2 compressive strength-volumetric water absorption diagram, compressive strength is increased as the water absorption ratio is decreased. In addition, relation with compressive strength –water absorption percent by volume-porosity- apparent density were shown in figure 8-9-10.



**Figure 6.** Coring from stone sample

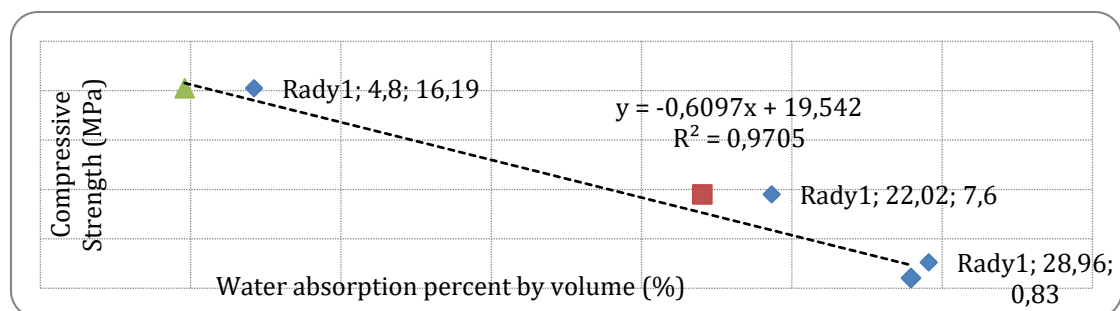




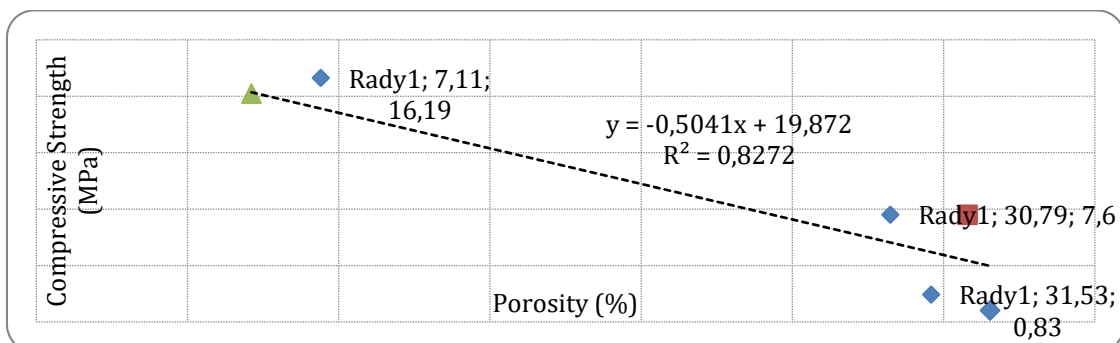
**Figure 7.** Uniaxial compression test of stone samples A, B, C respectively

**Table 2.** Compressive strength of stone samples

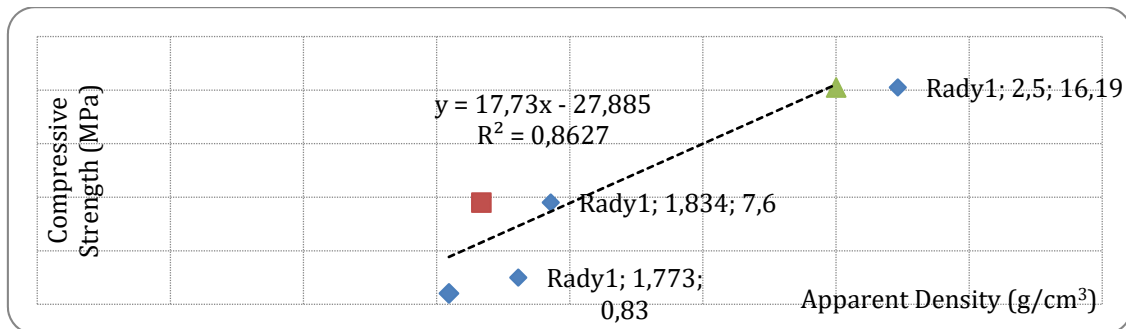
SAMPLES	Sk (%) Water absorption percent by weight	Sh (%) Water absorption percent by volume	$\Delta$ (gr/cm <sup>3</sup> ) Appareny Density	$\gamma$ (gr/cm <sup>3</sup> ) Real Density	Porosity (%)	Compression Strength MPa
TA	16,33	28,96	1,77	2,59	31,53	0,83
TB	12,01	22,02	1,83	2,65	30,79	7,60
TC	1,92	4,80	2,50	2,69	7,11	16,19
TD	11,51	20,94	1,82	2,66	31,53	Borehole weren't taken
TE	3,17	7,38	2,33	2,62	10,92	Borehole weren't taken



**Figure 8.** Relation with compressive strength - water absorption by volume of stone samples



**Figure 9.** Relation with compressive strength - porosity of stone sample



**Figure 10.** Relation with compressive strength – Apparent density of stone sample

## 5. Conclusions

Volumetric water absorption ratios of the mortars collected from the outer and inner facade of the wall were in the range of 23.24%-29.36%. True density and porosity values of the mortars were in the range of 2.35-2.75 g/cm<sup>3</sup> and 30.21-41.89%, respectively. These results suggested similarities between the mortars used in the outer and inner facade of the wall. There were no significant differences in the physical properties of the mortars collected from the outer and inner facade of the wall.

Volumetric water absorption ratios of the stones collected from the outer and inner facade of the wall were in the range of 4.8%-28.96%. True densities of the stones, on the other hand, were in the range of 2.59-2.69 g/cm<sup>3</sup>. Porosity of the stones was in the range of 7.11-31.53%. Physical experiments showed that there are significant differences between the stones used in the outer and inner facade of the wall. A closer look into the compressive strength of stones showed that compressive strength increases with decreasing porosity. Compressive strength of the stones increases with increasing apparent density. Based on the structure of the stones being sampled, compressive strength readings were above 15 MPa. It was observed that the properties of sedimentary rocks degrade when they are exposed to water. It was found that the findings of this study were similar to those reported in recent literature. In general, water absorption increases and compressive strength decreases with increasing porosity.

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