Avrupa Bilim ve Teknoloji Dergisi
Sayı 18, S. 621-635, Mart-Nisan 2020

Araştırma Makalesi

www.ejosat.com ISSN:2148-2683

European Journal of Science and Technology
No. 18, pp. 621-635, March-April 2020

Research Article

Increasing Mechanical Strength of Ignimbrite Rocks

Abdulrezzak Bakis[1*]

[1] Department of Civil Engineering, Faculty of Engineering-Architecture, Batman University, Batman, Türkiye (ORCID: 0000-0002-7487-884X)

(First received 10 February 2020 and in final form 18 March 2020)

(**DOI:** 10.31590/ejosat.687324)

ATIF/REFERENCE: Bakis, A. (2020). Increasing Mechanical Strength of Ignimbrite Rocks. *European Journal of Science and Technology*, (18), 621-635.

Abstract

Ignimbrite is a type of pyroclastic rock that is formed by the volcanic lava. With the explosion of the Nemrut crater in the city of Bitlis, the lava sprawling around it has cooled down. Because of these cooling, pyroclastic rocks, known as Ahlat stones (AS), were formed in the region. The compressive and bending strength of natural Ahlat stone is very low. In this study, the compressive and bending strength of natural Ahlat stone has been increased by the applications of drying oven curing and combined curing. Natural AS samples were cut into sizes of 150×150×150 mm for compressive test and of 100×100×400 mm for bending test. No cure was applied to some of the natural Ahlat stone samples brought from the quarry, which were selected as reference samples. 10 different cure types were applied to other natural Ahlat stones with the same characteristics as Reference Ahlat stone. These 10 different curing types included air curing, standard water curing, 4 drying oven curing types and 4 combined curing types. After curing, all samples were subjected to compressive and bending tests. Average compressive strength of the reference samples was found to be 9.8 MPa, and its bending strength was found to be 1.6 MPa. The highest average compressive strength of Ahlat stone was found to be 19.2 MPa after 3 days of drying oven curing at 200ºC. The highest average bending strength of Ahlat stone was found to be 3.2 MPa after 3 days of drying oven curing at 200ºC. The results of the study showed that the compressive and bending strength of the natural Ahlat stone can be increased to approximately 2 times after 3 days of drying oven curing at 200ºC.

Keywords: Ignimbrite rock, Heat treatments, Drying oven curing, Combined curing, Compressive strength, Bending strength.

İgnimbirit Kayaçlarının Mekanik Dayanımının Artırılması

Öz

İgnimbirit, volkanik lavlar tarafından oluşturulan piroklastik bir kayaç türüdür. Bitlis ilinde Nemrut kraterinin patlamasıyla etrafa yayılan lavlar soğumuştur. Bu soğuma nedeniyle bölgede Ahlat taşı (AT) olarak bilinen piroklastik kayaçlar oluşmuştur. Doğal Ahlat taşının basınç ve eğilme dayanımı çok düşüktür. Bu çalışmada, etüv kürü ve kombine kür uygulamalarıyla doğal Ahlat taşının basınç ve eğilme dayanımı arttırılmıştır. Doğal AT numuneleri basınç deneyi için 150×150×150 mm ve eğilme deneyi için 100×100×400 mm boyutlarında kesilmiştir. Taş ocağından getirilen ve referans örnekleri olarak seçilen doğal Ahlat taşı numunelerinin hiçbirine kür uygulanmamıştır. Referans Ahlat taşı ile aynı özelliklere sahip diğer doğal Ahlat taşlarına ise 10 farklı kür tipi uygulandı. Bu 10 farklı kür tipi; hava kürü, standart su kürü, 4 tip etüv kürü ve 4 tip kombine kürü içermektedir. Kür sonrası tüm numunelere basınç ve eğilme deneyi uygulandı. Referans numunelerinin ortalama basınç dayanımı 9,8 MPa ve ortalama eğilme dayanımı 1,6 MPa olarak bulundu. Ahlat taşının en yüksek ortalama basınç dayanımı, 200ºC' de 3 günlük etüv küründen sonra 19,2 MPa olarak bulundu. Ahlat taşının en yüksek ortalama eğilme dayanımı, 200ºC' de 3 günlük etüv küründen sonra 3,2 MPa olarak bulundu. Çalışma sonuçları, doğal Ahlat taşının basınç ve eğilme dayanımının, 200ºC' de 3 günlük etüv küründen sonra yaklaşık iki katına çıkarılabileceğini gösterdi.

Anahtar Kelimeler: İgnimbirit kayaç, Isıl işlemler, Etüv kürü, Kombine kür, Basınç dayanımı, Eğilme dayanımı.

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[*] Corresponding Author: Department of Civil Engineering, Faculty of Engineering-Architecture, Batman University, Batman, Turkey, ORCID: 0000-0002-7487-884X, abdulrezzak.bakis@batman.edu.tr

1. Introduction

Because of volcanic eruptions in high gas pressure, granular volcanic rocks are formed. One of these products is pyroclastic rocks (Gevrek and Kazanci, 1994; Simsek and Erdal, 2004). Prophylactic currents rich in pumice are named ignimbrites (Karaman and Kibici, 2008). Ignimbrite is a type of pyroclastic rock that is formed by the volcanic lava flowing to the environment. With the explosion of the Nimrod crater in the city of Bitlis, the lava sprawling around the crater eventually cooled down (Ulusoy et al, 2019; Akkopru and Christol, 2019). Because of these cooling, pyroclastic rocks, known as Ahlat stones (AS) with their regional name, were formed. From the lava erupting from the Bitlis Nimrod crater, it was observed that approximately 100 km^3 of pyroclastic material was spread to the environment, and these were in the form of ignimbrites with different thicknesses (Aydar et al, 2003). Ahlat stone is easily processed because of its volcanic origin. It is a lightweight and long-lasting stone with good insulation (Boran, 1997; Ozvan et al, 2015; Aygun and Aygun, 2016). The durability of Ahlat stone is very low due to the pores inside (Baykara and Isik, 2016; Akin et al, 2017; Kuluozturk, 2018; Ertugral and Gunay, 2019). Thus, areas of use of Ahlat stone are limited today. It is mainly used in the construction of stonewalls, tombstones, mosques and domes in the region. It can be used in areas such as Ahlat stone, road surface where hardening process is performed. On the hardened Ahlat stone road surface, the maintenance factor will be beneficial in terms of wear (Eren et al, 2017; Cengiz and Cengiz, 2018; Cengiz, 2019). One of the factors affecting the compressive and bending strength of building materials is heat-treated curing. The aim of the heat-treated curing is to shorten the curing time of the material.

Drying oven curing and combined curing are heat-treated curing methods. Combined curing is the succession of several different cures without interruption. In the literature, no studies were encountered on drying oven curing and combined curing of natural Ahlat stone. For improving the compressive and bending strength of natural Ahlat stone, a total of 10 different curing types including air curing, standard water curing, 4 drying oven curing types and 4 combined curing types were applied to Ahlat stone in this study. The aim of this study was to extend the use of Ahlat stone in the construction sector. After different curing methods, the compressive and bending tests of all samples were done. Besides, tensile strength, Elasticity Modulus and other physical-mechanic properties of Ahlat stones were calculated.

The compressive and bending strength of natural Ahlat stone is very low. In this study, the compressive and bending strength of natural Ahlat stone has been increased by the applications of drying oven curing and combined curing. After curing, all samples were subjected to compressive and bending tests. The results of the study showed that the compressive and bending strength of the natural Ahlat stone can be increased after drying oven curing and combined curing.

2. Materials and Methods

2.1. Materials

Ahlat stone was obtained from the Ahlat Ovakisla quarry. The natural Ahlat stones extracted from the stone quarry are seen in Fig. 1.

Fig. 1. Natural Ahlat Stones

The chemical properties of Ahlat stone are seen in Table 1 (Simsek and Erdal, 2004). It is stated that the sum of SiO_2 + Al_2O_3 + Fe_2O_3 should be at least 70% in Trass Standard (TS 25/T1, 2011).

Table 1. The Chemical Properties of Ahlat Stone

Component	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	Fe_2O_3
Percentage (%)	5.51	0.24	16.01	64.11	4.78	1.64	0.44	4.91

As shown in Table 1, the sum of $SiO_2 + Al_2O_3 + Fe_2O_3$ of Ahlat stone is 85.03%. It was shown that grinded Ahlat stone could be used as binder with cement and lime (Hattatoglu and Bakis, 2017).

2.2. Methods

2.2.1. Preparation of Natural Ahlat Stone Samples

AS samples were cut into sizes of 150×150×150 mm for compressive test and of 100×100×400 mm for bending test. The appearance of Ahlat stone after cutting is seen in Fig. 2.

Fig. 2. The Appearance of Natural Ahlat Stone after Cutting

2.2.2. Specific Gravity and Unit Weight Tests of Natural Ahlat Stone

Specific gravity values of natural Ahlat stone were calculated according to the TS EN 1097-6:2015 standard (TS EN 1097-6, 2013). In determining the specific gravity of natural Ahlat stone, remaining materials on sieve No. 4 were taken into account. In the specific gravity determination of Ahlat stone filler aggregates, passing materials from sieve No. 200 were taken into consideration. Water was filled until closing filler materials in pycnometer. Later, filler materials in pycnometer were vacuumed by heating. Pycnometer with vacuumed samples were filled in with water and left in water bath at 25°C for 24 hours. The pycnometer removed from water bath were dried and weighed. Specific gravity (ρ) of natural Ahlat stone was calculated from Eq. (1) in terms of g/cm^3.

$$\rho = \frac{M4}{M4 - (M2 - M3)} \tag{1}$$

Denotes in Eq. (1):

M2: Pycnometer weight + weight of water-saturated specimen + water weight in pycnometer
M3: Pycnometer weight + water weight in pycnometer
M4: Weight of dried specimen in drying oven

Unit weight (Δ) of natural Ahlat stone was calculated from Eq. (2) in terms of g/cm^3. In the study, sample volume (V) was 3375 cm^3 in total as to be 150×150×150 mm.

$$\Delta = \frac{Wd}{V} \tag{2}$$

Denotes in Eq. (2):

Wd: Weight of dried sample in drying oven, g
V: Sample volume, cm^3

2.2.3. Porosity and Compactness Calculation of Natural Ahlat Stone

Porosity (P) of natural Ahlat stone was calculated from Eq. (3) in terms of percentage.

$$P = (1 - \frac{\Delta}{\rho}) \times 100 \tag{3}$$

Compactness (C) of natural Ahlat stone was calculated from Eq. (4) in terms of percentage.

$$C = \frac{\Delta}{\rho} \times 100 \tag{4}$$

2.2.4. Calculation of Solid and Void Volumes of Natural Ahlat Stone

Solid volume (Vs) value of natural Ahlat stone was calculated from Eq. (5) in terms of cm^3.

$$\mathrm{Vs} = \frac{\mathrm{Wd}}{\rho} \tag{5}$$

Denotes in Eq. (5):

Wd: Weight of dried sample in drying oven, g
Void volume (Vv) value of natural Ahlat stone was calculated from Eq. (6) in terms of cm^3.

$$\mathrm{Vv} = \mathrm{V} - \mathrm{Vs} \tag{6}$$

Sample volume (V) was 3375 cm^3 in total as to be 150×150×150 mm.

2.2.5. Water Absorption Test of Natural Ahlat Stone

The water absorption value of natural Ahlat stone was calculated according to the TS 2824 EN 1338 standard (Unsal and Sen, 2008). In the study, the samples were left in the curing pool at 20±5°C for 3 days until constant weight. The samples were then removed from the curing pool, dried and weighed. In this way, the initial weight (M1) of the test samples was found. The samples were then placed in the drying oven and dried at 105±5ºC for 3 days until constant dry weight (M2) was reached. The water absorption (Waw) of natural Ahlat stone was calculated from Eq. (7) in terms of percentage by weight (Unsal and Sen, 2008; Bakis, 2019).

$$\mathrm{Waw} = \frac{(\mathrm{M1} - \mathrm{M2})}{\mathrm{M2}} \times 100 \tag{7}$$

The water absorption (Wav) of natural Ahlat stone was calculated from Eq. (8) in terms of percentage by volume. Sample volume (V) was 3375 cm^3 (150×150×150 mm).

$$\mathrm{Wav} = \frac{(\mathrm{M1} - \mathrm{M2})}{\mathrm{V}} \times 100 \tag{8}$$

For the water absorption value, three samples from natural Ahlat stones were taken, and the average of these three values was calculated.

2.2.6. Calculation of Saturation Level of Natural Ahlat Stone

Saturation level (SL) of natural Ahlat stone was calculated from Eq. (9) in terms of percentage.

$$\mathrm{SL} = \frac{\mathrm{Wav}}{\mathrm{P}} \times 100 \tag{9}$$

The degree of saturation is important in that it demonstrates the freezing resistance of a material. If the ice due to frost does not completely fill the cavities, the pressure due to frost does not affect the material and does not damage the material. However, if the air temperature constantly falls, the gaps are completely filled with ice, and if the heat continues to fall, the material is unable to withstand the pressure of the ice and will eventually crack and break up. Therefore, to have frost damage in a material, the degree of saturation must generally be 80% and above (Eric, 1982).

2.2.7. Los Angeles Abrasion Test

Los Angeles abrasion value (LA) of natural Ahlat stone was calculated from Eq. (10) in terms of percentage. The Los Angeles abrasion test was done according to the TS EN 1097-2 (2015) standard. This test determines the abrasion resistance of coarse-grained stone aggregates by the Los Angeles machine. A total of 5000±5 grams of Ahlat stone aggregates were used in the test. The timer was adjusted to a speed of 32 rpm per minute and to a maximum of 500 cycles.

$$\mathrm{LA} = \frac{(5000 - \mathrm{m})}{50} \tag{10}$$

After 500 cycles of the Los Angeles abrasion test device, Ahlat stone aggregates were removed from the device. Ahlat stone aggregates retained on the 1.6 mm sieve were then placed in the drying oven and dried at 110±5ºC until constant dry weight (m) was reached.

2.2.8 Curing Types of Ahlat Stone

No cure was applied to some of the Ahlat stone samples brought from the quarry, which were selected as the reference Ahlat stones (R). 10 different curing types were applied to the other natural Ahlat stones. These included air curing, standard water curing, 4 drying oven curing types and 4 combined curing types. Combined curing is the succession of several different curing methods without interruption.

No standard is found in the literature for drying oven curing and combine curing. It was stated in a study that the curing method providing the highest compressive and bending strength was the combined curing applied as water curing at 20ºC for 7 days, water bath curing at 90ºC for 2 days and drying oven curing at 180ºC for 2 days (Hattatoglu and Bakis, 2017).

Table 2. Curing Types Applied to Ahlat Stone Samples

Sample no	Curing description	Curing types
R	No curing applied	No curing
1	7 days air curing at 20°C	Air curing
2	7 days water curing at 20°C	Standard water curing
3	1 day drying oven curing at 200°C	Drying oven curing-1
4	2 days drying oven curing at 200°C	Drying oven curing-2
5	3 days drying oven curing at 200°C	Drying oven curing-3
6	4 days drying oven curing at 200°C	Drying oven curing-4
7	7 days water curing+1 day drying oven curing at 200°C	Combined curing-1
8	7 days water curing+2 days drying oven curing at 200°C	Combined curing-2
9	7 days water curing+3 days drying oven curing at 200°C	Combined curing-3
10	7 days water curing+4 days drying oven curing at 200°C	Combined curing-4

As shown in Table 2, different types of curing methods were applied to Ahlat stone samples in this study.

Fig. 3. (a) Curing Pool (b) Drying Oven

Ahlat stone samples for water curing pool and drying oven are seen in Fig. 3.

2.2.9. Compressive and Bending Strength Tests of Ahlat Stones

After curing, all samples were applied compressive and bending tests. TS EN 12390-5 (2010) standard was applied in the bending test. The TS EN 12390-3 (2010) standard was applied in the compressive test. In the specification limits, the minimum bending strength is required to be 4.5 MPa, and the minimum compressive strength is required to be 28 MPa in proportion to the road pavement (Tunc, 2007). Bending and compressive test devices are seen in Fig. 4.

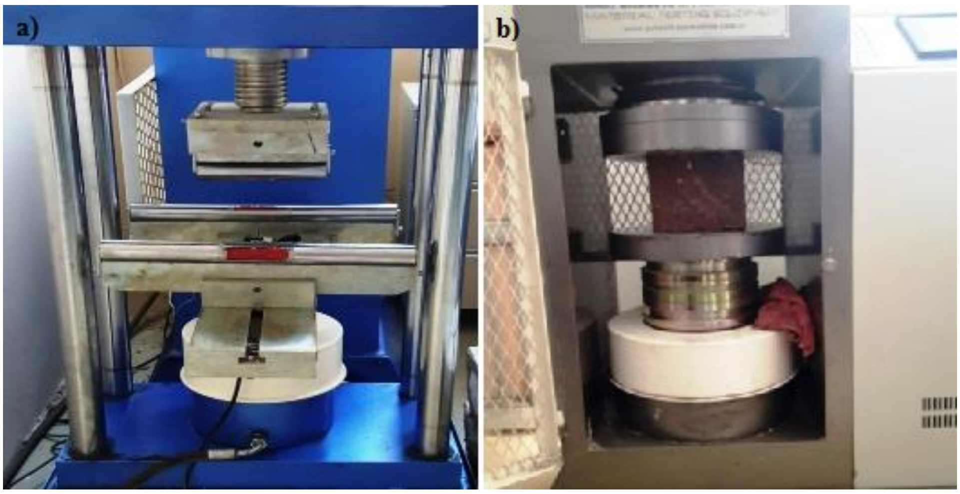

Fig. 4. (a) Bending Test Device (b) Compressive Test Device

2.2.10. Calculation of Elasticity Modulus and Tensile Strength

Elasticity Modulus and tensile strength of Ahlat stones were calculated according to Eq. (11) and Eq. (12), respectively (TS 500, 2000).

$$\mathrm{Ec} = (3250 \times \sqrt{\mathrm{Fck}} + 14000 \tag{11}$$

$$\mathrm{Fctk} = 0.35 \times \sqrt{\mathrm{Fck}} \tag{12}$$

Denotes in Eq. (11) and Eq. (12):

Ec: Elasticity Modulus, MPa
Fck: Characteristic cylinder compressive strength, MPa
Fctk: Tensile strength, MPa

The characteristic cylinder compressive strength of the Ahlat stones can be taken as 0.8 times the cube compressive strength (TS 500, 2000). In this study, Ahlat stones were prepared as cubes. Therefore, 0.8 times the cube compressive strengths were determined, and characteristic cylinder compressive strength of Ahlat stones was calculated.

2.2.11. Calculation of Shear Modulus of Natural Ahlat Stone

Shear modulus (G) value of natural Ahlat stone was calculated from Eq. (13) in terms of MPa (TS 500, 2000). Poisson ratio can be taken as 0.20 for Ahlat stone ignimbrite (Akkaya et al, 2019).

$$\mathrm{G} = \frac{\mathrm{E}}{2 \times (1 + \sigma)} \tag{13}$$

Denotes in Eq. (13):

E: Elasticity Modulus, MPa
σ: Poisson ratio
G: Shear modulus, MPa

3. Results and Discussion

3.1. Specific Gravity and Unit Weight Test Results of Natural Ahlat Stone

Specific gravity values of Ahlat stone are seen in Table 3.

Table 3. Specific Gravity Values of Ahlat Stone

Sample no	M2 (g)	M3 (g)	M4 (g)	M2-M3 (g)	M4-(M2-M3) (g)	Specific gravity (ρ) (g/cm^3)
1	451.75	427.52	40	24.23	15.77	2.536
2	454.82	430.56	40	24.26	15.74	2.541
3	452.67	428.63	40	24.04	15.96	2.506
Average	453.08	428.90	40	24.18	15.82	2.528

For the specific gravity value, three samples from Ahlat stones were taken, and the average of these three values was calculated.

Table 4. Unit Weight Values of Ahlat Stone

Sample no	Weight of dried sample (g)	Volume (cm^3)	Unit weight (Δ) (g/cm^3)
1	5440	3375	1.612
2	5390	3375	1.597
3	5540	3375	1.641
Average	5457	3375	1.617

Unit weight values of Ahlat stone are seen in Table 4. Low unit weight of Ahlat stone indicates that it has a porous structure.

3.2. Porosity and compactness of natural Ahlat stone

The porosity of Ahlat stone is seen in Table 5. Low compactness and high porosity of Ahlat stone indicates that it has a porous structure.

Table 5. Porosity of Ahlat stone

Sample no	Unit weight (Δ) (g/cm^3)	Specific gravity (ρ) (g/cm^3)	Compactness (Δ / ρ) (%)	Porosity (P) (%)
1	1.612	2.536	64	36
2	1.597	2.541	63	37
3	1.641	2.506	65	35
Average	1.617	2.528	64	36

3.3. Solid and Void Volumes of Natural Ahlat Stone

Solid volume (Vs) and void volume (Vv) values of natural Ahlat stone are seen in Table 6.

Table 6. Solid volume and void volume values of natural Ahlat stone

Sample no	Specific gravity (ρ) (g/cm^3)	Weight of dried sample (Wd) (g)	Total volume (cm^3)	Vs (cm^3)	Vv (cm^3)
1	2.536	5440	3375	2145	1230
2	2.541	5390	3375	2121	1254
3	2.506	5540	3375	2211	1164
Average	2.528	5457	3375	2159	1216

Low void volume and high solid volume of Ahlat stone indicates that it has a porous structure.

3.4. Water absorption of natural Ahlat stone

Water absorption values of Ahlat stone are seen in Table 7 (Bakis, 2019).

Table 7. Water Absorption Values of Ahlat Stone

Sample no	M1 (g)	M2 (g)	Volume (cm^3)	Wav (%)	Waw (%)
1	6450	5440	3375	29.9	18.6
2	6370	5390	3375	29.0	18.2
3	6570	5540	3375	30.5	18.5
Average	6463	5457	3375	29.8	18.4

Due to the high porosity of Ahlat stone, its water absorption value is high, as seen in Table 7.

3.5. Saturation Level of Natural Ahlat Stone

Saturation level values of Ahlat stone are seen in Table 8.

Table 8. Saturation Level Values of Ahlat Stone

Sample no	Water absorption by volume (Wav) (%)	Porosity (P) (%)	Saturation level (SL) (%)
1	29.9	36	83
2	29.0	37	78
3	30.5	35	87
Average	29.8	36	83

Because water saturation level of Ahlat stone is 83% as seen in Table 8, natural Ahlat stone is not durable against freezing.

3.6. Los Angeles Abrasion Test Results of Natural Ahlat Stone

Los Angeles abrasion coefficient of Ahlat stones is seen in Table 9.

Table 9. Los Angeles abrasion coefficient of Ahlat stones

Sample no	Specimen weight (g)	m (g)	LA (%)
1	5000	1290	74
2	5000	1248	75
3	5000	1271	75
Average	5000	1270	75

Due to the high porosity of Ahlat stone, its Los Angeles abrasion value is high, as seen in Table 9.

3.7. Compressive and Bending Test Results of Ahlat Stones

3.7.1. Compressive and Bending Test Results of Natural Ahlat Stones

Because the porosity, water absorption and Los Angeles abrasion values of Ahlat stone are high, its compressive and bending strength is low, as seen in Table 10.

Table 10. Compressive and Bending Test Results of Ahlat Stone

Sample no.	Unit weight (g/cm^3)	Compressive strength (MPa)	Bending strength (MPa)
R1	1.612	10.0	1.5
R2	1.597	10.3	1.8
R3	1.641	9.1	1.4
Average	1.617	9.8	1.6

3.7.2. Compressive and Bending Test Results of Ahlat Stones after Different Curing

Compressive and bending test results after different curing types of Ahlat stone are seen in Table 11. As shown in Table 11, the maximum bending and compressive strength of Ahlat stone were obtained after drying oven curing-3 (3 days drying oven curing at 200°C-Sample No. 5).

Table 11. Maximum Compressive and Bending Strength of Ahlat Stone after Different Curing Types

Sample no	Curing types	Compressive strength (MPa)	Bending strength (MPa)
R	No curing applied	9.8	1.6
1	7 days air curing at 20°C	13.9	2.5
2	7 days water curing at 20°C	12.4	2.1
3	1 day drying oven curing at 200°C	15.6	2.6
4	2 days drying oven curing at 200°C	17.1	2.9
5	3 days drying oven curing at 200°C	19.2	3.2
6	4 days drying oven curing at 200°C	12.8	2.1
7	7 days water curing+1 day drying oven curing at 200°C	13.5	2.4
8	7 days water curing+2 days drying oven curing at 200°C	15.4	2.6
9	7 days water curing+3 days drying oven curing at 200°C	17.2	2.9
10	7 days water curing+4 days drying oven curing at 200°C	10.5	1.8

According to Table 11, the compressive and bending strength of Ahlat stone decrease in 7 days water curing at 20°C but increase in 7 days air curing at 20°C.

Fig. 5. Ahlat Stone Samples Broken After (a) Air Curing and (b) Water Curing

Ahlat stone samples that were broken in compressive test device after 7 days air curing at 20°C (sample no. 1) are shown in Fig. 5 (a). Ahlat stone samples that were broken in compressive test device after 7 days water curing at 20°C (sample no. 2) are shown in Fig. 5 (b). Ahlat stone samples that were broken in compressive test device after drying oven curing (sample no. 3) are shown in Fig. 6 (a). Ahlat stone samples that were broken in compressive test device after drying oven curing (sample no. 4) are shown in Fig. 6 (b). Ahlat stone samples that were broken in compressive test device after drying oven curing (sample no. 5) are shown in Fig. 6 (c). Ahlat stone samples that were broken in compressive test device after drying oven curing (sample no. 6) are shown in Fig. 6 (d). The maximum compressive strength of Ahlat stone was obtained from sample no. 5 after drying oven curing.

Fig. 6. Ahlat Stone Samples Broken after Drying Oven Curing

The Ahlat stone samples that were broken in compressive test device after combined curing (sample no. 7, 8, 9 and 10) are shown in Fig. 7 (a). The Ahlat stone samples that were broken in compressive test device after combined curing (sample no. 7, 8, 9 and 10) are shown in Fig. 7 (b). The Ahlat stone samples that were broken in compressive test device after combined curing (sample no. 7, 8, 9 and 10) are shown in Fig. 7 (c). The Ahlat stone samples that were broken in compressive test device after combined curing (sample no. 7, 8, 9 and 10) are shown in Fig. 7 (d).

Fig. 7. Ahlat Stone Samples Broken after Combined Curing

The maximum compressive strength of Ahlat stone was obtained from sample no. 9 after combined curing. Fig. 8 shows the compressive strength of Ahlat stone after drying oven curing and combined curing. As shown in Fig. 8, the maximum compressive strength of Ahlat stone was obtained from sample no. 5 after drying oven curing.

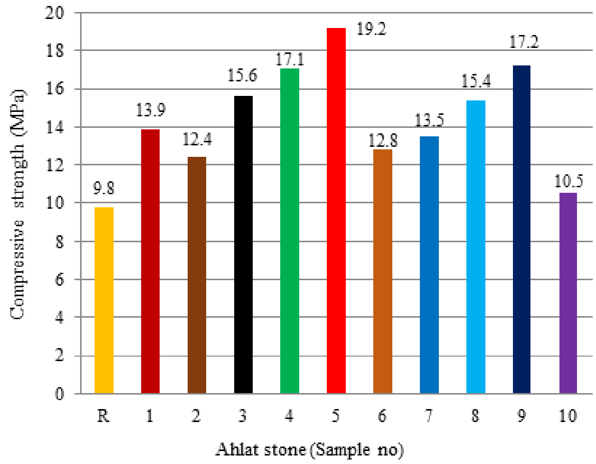

Fig. 8. Compressive strength of Ahlat stone after drying oven curing and combined curing

The relationship between compressive strength and drying oven time in drying oven curing is seen in Fig. 9.

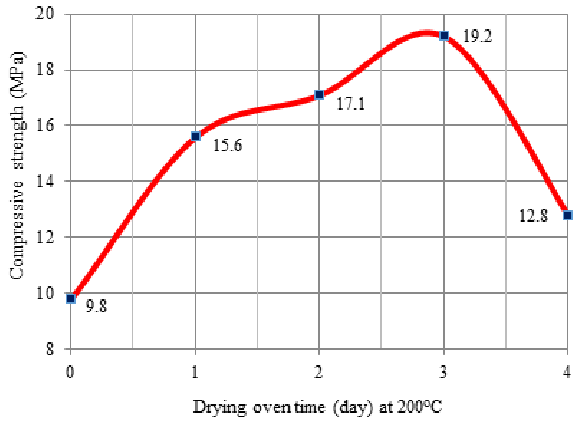

Fig. 9. The Relationship between Compressive Strength and Drying Oven Time in Drying Oven Curing

As shown in Fig. 9, the maximum compressive strength of Ahlat stone was obtained from 3 days drying oven curing at 200°C. The highest compressive strength of Ahlat stone was found to be 19.2 MPa. The maximum compressive strength of Ahlat stone was obtained from combined curing (7 days water curing +3 days drying oven curing at 200°C).

The highest compressive strength of Ahlat stone was found to be 17.2 MPa. The relationship between compressive strength and drying oven time in combined curing is seen in Fig. 10.

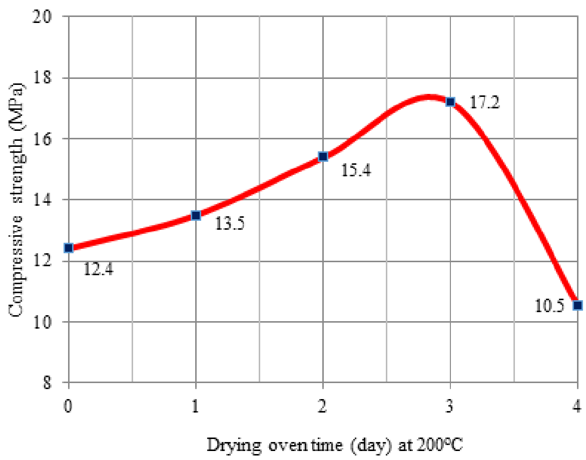

Fig. 10. The Relationship between Compressive Strength and Drying Oven Time in Combined Curing

The maximum compressive strength of Ahlat stone after different curing types is seen in Fig. 11.

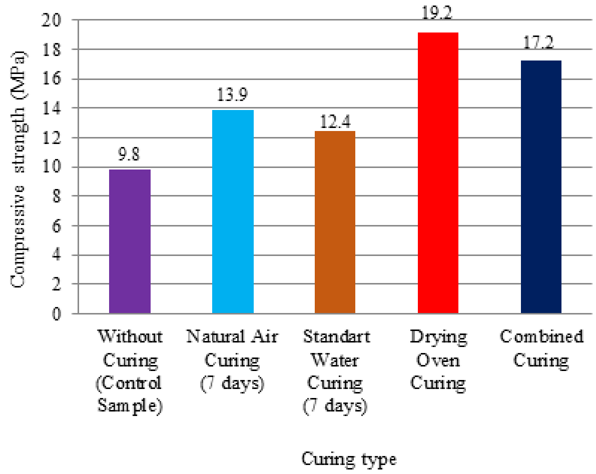

Fig. 11. Maximum Compressive Strength of Ahlat Stone after Different Curing Types

As shown in Fig. 11, the maximum compressive strength of Ahlat stone was obtained from drying oven curing. The bending strength of Ahlat stone after drying oven curing and combined curing is seen in Fig. 12.

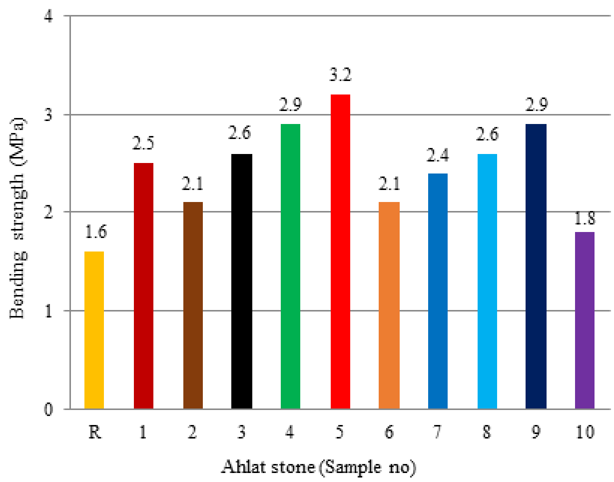

Fig. 12. Bending Strength after Drying Oven Curing and Combined Curing of Ahlat Stone

As shown in Fig. 12, the maximum bending strength of Ahlat stone was obtained after drying oven curing-3 (3 days drying oven curing at 200°C). The highest bending strength of Ahlat stone was found to be 3.2 MPa.

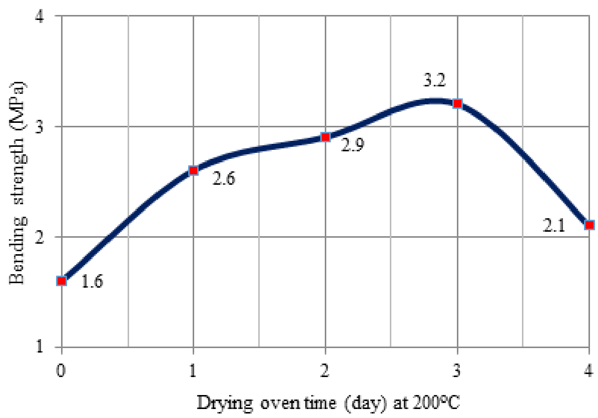

Fig. 13. The Relationship between Bending Strength and Drying Oven Time in Drying Oven Curing

The relationship between bending strength and drying oven time in drying oven curing is seen in Fig. 13. The highest bending strength of Ahlat stone was found to be 3.2 MPa in drying oven curing. The relationship between bending strength and drying oven time in combined curing is seen in Fig. 14.

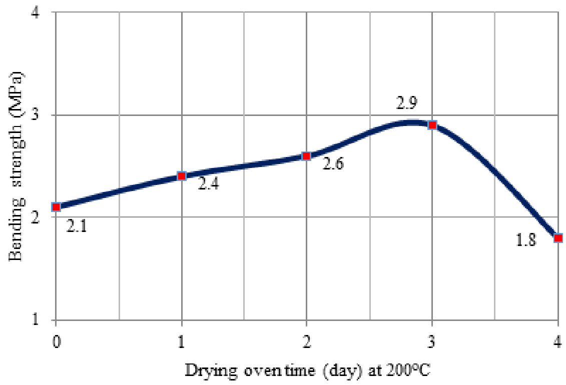

Fig. 14. The Relationship between Bending Strength and Drying Oven Time in Combined Curing

The relationship between bending strength and drying oven time in combined curing is seen in Fig. 14. The highest bending strength of Ahlat stone was found to be 2.9 MPa in combined curing. The maximum bending strength of Ahlat stone after different curing types is seen in Fig. 15.

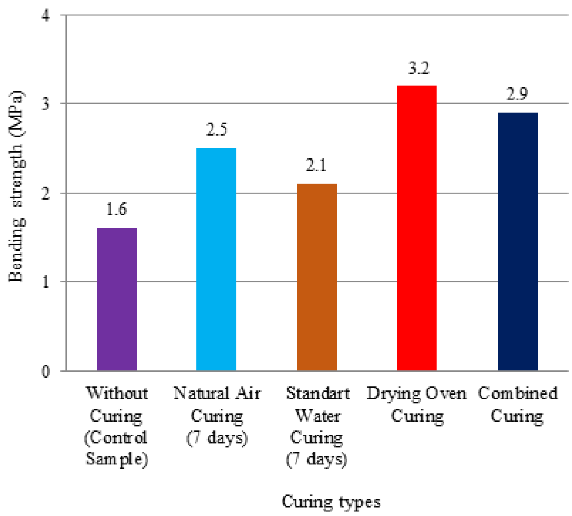

Fig. 15. Maximum Bending Strength of Ahlat Stone after Different Curing Types

As shown in Fig. 15, the maximum bending strength of Ahlat stone was obtained from drying oven curing.

3.8. Elasticity Modulus and Tensile Strength of Ahlat Stone

Elasticity Modulus and tensile strength results of Ahlat stones are shown in Table 12.

Table 12. Elasticity Modulus and Tensile Strength of Ahlat Stone

Sample No	Curing types	Elasticity Modulus (MPa)	Tensile strength (MPa)
R	No curing applied	23100	1.0
1	7 days air curing at 20°C	24838	1.2
2	7 days water curing at 20°C	24236	1.1
3	1 day drying oven curing at 200°C	25481	1.2
4	2 days drying oven curing at 200°C	26021	1.3
5	3 days drying oven curing at 200°C	26737	1.4
6	4 days drying oven curing at 200°C	24400	1.1
7	7 days water curing+1 day drying oven curing at 200°C	24681	1.2
8	7 days water curing+2 days drying oven curing at 200°C	25407	1.2
9	7 days water curing+3 days drying oven curing at 200°C	26056	1.3
10	7 days water curing+4 days drying oven curing at 200°C	23419	1.0

As shown in Table 12, the maximum Elasticity Modulus and tensile strength in Ahlat stone types were obtained after drying oven curing. The maximum Elasticity Modulus and tensile strength in Ahlat stone types were obtained from sample no 5. Calculation results of Elasticity Modulus are seen in Fig. 16.

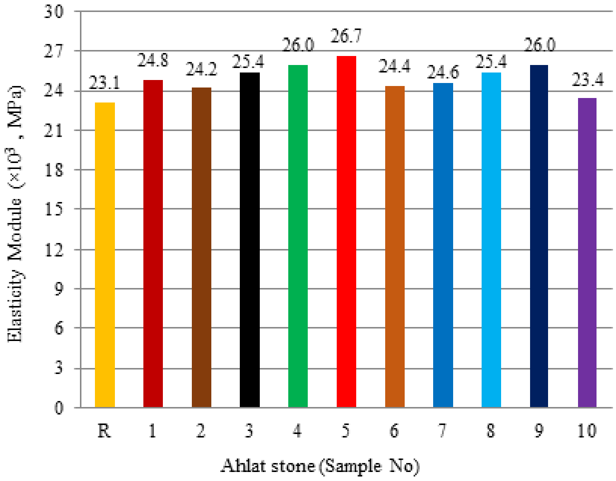

Fig. 16. Elasticity Modulus Value of Ahlat Stones

As shown in Fig. 16, the maximum Elasticity Modulus in Ahlat stone types was obtained from sample no 5. Calculation results of tensile strength are seen in Fig. 17.

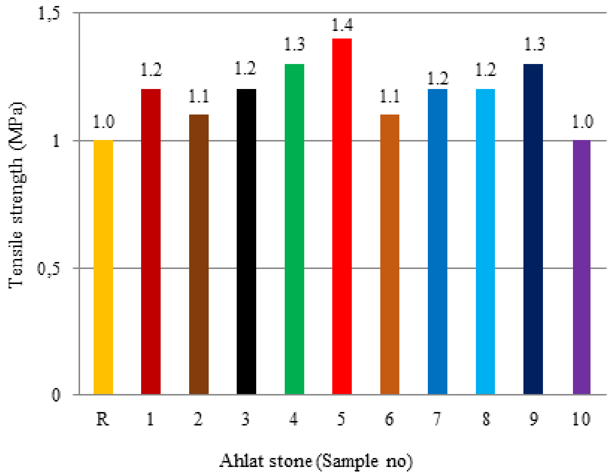

Fig. 17. Tensile Strength Values of Ahlat Stones

As shown in Fig. 17, the maximum tensile strength in Ahlat stone types was obtained from sample no 5.

3.9. Shear modulus (Rigidity Modulus) of Ahlat stone

Shear modulus calculation results of Ahlat stones are shown in Table 13.

Table 13. Shear modulus calculation results of Ahlat stone

Sample No	Curing types	Shear modulus (MPa)
R	No curing applied	9625
1	7 days air curing at 20°C	10349
2	7 days water curing at 20°C	10098
3	1 day drying oven curing at 200°C	10617
4	2 days drying oven curing at 200°C	10842
5	3 days drying oven curing at 200°C	11140
6	4 days drying oven curing at 200°C	10167
7	7 days water curing+1 day drying oven curing at 200°C	10284
8	7 days water curing+2 days drying oven curing at 200°C	10586
9	7 days water curing+3 days drying oven curing at 200°C	10857
10	7 days water curing+4 days drying oven curing at 200°C	9758

As shown in Table 13, the maximum Shear Modulus in Ahlat stone types was obtained after drying oven curing.

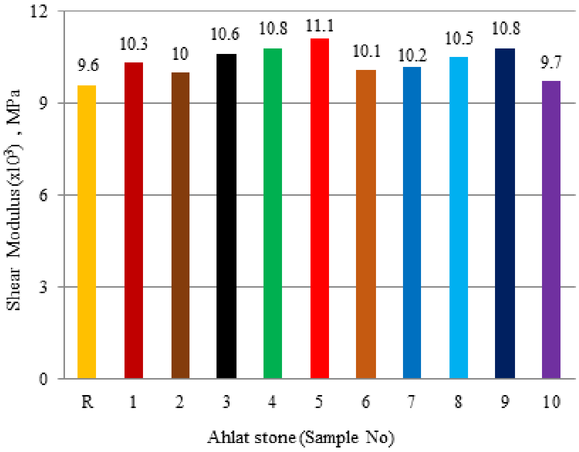

Fig. 18. Shear Modulus Value of Ahlat Stones

The maximum Shear modulus value in Ahlat stone types was obtained from sample no. 5. Calculation results of Shear Modulus are seen in Fig. 18.

3.10. The Physical and Mechanic Properties of Natural Ahlat Stone According to Test Results

According to the test and calculation results, the physical and mechanic properties of natural Ahlat stone are seen in Table 14.

Table 14. The Physical and Mechanic Properties of Natural Ahlat Stone

Properties	Value
Unit weight, g/cm^3	1.617
Water absorption by weight, %	18.4
Water absorption by volume, %	29.8
Specific gravity, g/cm^3	2.528
Porosity, %	36
Compactness, %	64
Solid volume of 1 cm^3 Ahlat stone	0.64
Void volume of 1 cm^3 Ahlat stone	0.36
Saturation level, %	83
Los Angeles abrasion test, %	75
Elasticity Modulus, MPa	23100
Tensile strength, MPa	1.0
Shear modulus, MPa	9625
Compressive strength, MPa	9.8
Bending strength, MPa	1.6

Low unit weight of Ahlat stone indicates that Ahlat stone has a porous structure. Therefore, Los Angeles abrasion loss of Ahlat stone was obtained to be high.

4. Conclusion

In this study, the compressive and bending strength of ignimbrite rocks (natural Ahlat stone) was increased by the applications of drying oven curing and combined curing. The bending and compressive strength of Ahlat stone after drying oven curing and combined curing were higher than the reference Ahlat stone samples. The maximum compressive strength of Ahlat stone was found as 19.2 MPa after drying oven curing. Moreover, the maximum bending strength of Ahlat stone was found as 3.2 MPa after the same curing. By changing the curing type, the compressive and bending strength of Ahlat stone can be increased. In the specification limits, the minimum bending strength is required to be 4.5 MPa, and the minimum compressive strength is required to be 28 MPa in proportion to the rigid road pavement. Therefore, natural Ahlat stone cannot be used instead of rigid road pavement. The compressive and bending strength of Ahlat stone in air curing was higher than the compressive and bending strength of Ahlat stone in water curing. The compressive and bending strength of Ahlat stone is increased in natural air conditions day by day. Ahlat stone is a stone with pozzolanic properties. It can be said that building materials with pozzolanic properties exhibit better resistance in natural environment conditions. The compressive and bending strength of Ahlat stone decrease in water. Therefore, natural Ahlat stone is not suitable for underwater structures such as bridge feet.

Acknowledgements

We would like to thank the Rector of Bitlis Eren University who provided all his support in our studies and the Van lake Building Quality Control Laboratory Construction Industry Trade Limited Company.

References

Akin, M., Ozvan, A., Dincer, I., Topal, T. (2017). Evaluation of the physico-mechanical parameters affecting the deterioration rate of Ahlat ignimbrites (Bitlis, Turkey), *Environmental earth sciences*, *76*(24), pp. 827. https://doi.org/10.1007/s12665-017-7175-7

Akkaya, I., Ozvan, A., Tapan, M., Bor, M., Ozvan, E. E. (2017). Determination of the Relationship between Poisson's Ratio and Physical, Mechanical and Chemical Properties of Different Type Rocks, *National Symposium on Engineering Geology and Geotechnics*, Cukurova University, Adana, pp. 208–215.

Akkopru, E., Christol, A. (2019). Lake Van, *Landscapes and Landforms of Turkey*, pp. 369–382, https://doi.org/10.1007/978-3-030-03515-0_18

Aydar, E., Gourgaud, A., Ulusoy, I., Digonnet, F., Labazuy, P., Sen, E. (2003). Morphological Analysis of Active Mount Nemrut Stratovolcano, Eastern Turkey: Evidences and Possible Impact Areas of Future Eruption, *Journal of Volcanology and Geothermal Research*, *123*, pp. 301–312, https://doi.org/10.1016/S0377-0273(03)00002-7

Aygun, Z., Aygun, M. (2016). Spectroscopic analysis of Ahlat stone (ignimbrite) and pumice formed by volcanic activity, *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *166*, pp. 73–78. https://doi.org/10.1016/j.saa.2016.05.018

Bakis, A. (2019). Determination of Water Absorption of Natural Ahlat Stone, *International Engineering and Science Symposium*, Siirt University, Siirt, pp. 335–337.

Baykara, T., Isik, M. C. (2016). Physical characterization, microstructural evaluation, and condition assessment of Ancient Ahlat Tombstones in the Seljukian Cemetery of Ahlat (Turkey), *International Journal of Architectural Heritage*, *10*(8), pp. 1025–1040. https://doi.org/10.1080/15583058.2016.1181227

Boran, A. (1997). Ahlat Stone (Andesite Tuff) (in Turkish), *Vakiflar Journal*, *26*, pp. 363–373.

Cengiz, M. S., Cengiz, C. (2018). Numerical Analysis of Tunnel LED Lighting Maintenance Factor. IIUM Engineering Journal, vol. 19(2), pp. 154–163.

Cengiz, M. S. (2019). The Relationship Between Maintenance Factor and Lighting Level in Tunnel Lighting. Light & Engineering, vol. 27. 3, pp. 154–163.

Eren, M., Kaynaklı, M., Yapici, I., Gencer, G., Yurci, Y., Cengiz, M. S., Cengiz, C. (2017). Numerical Analysis of Maintanance Factor for Tunnel and Road in Solid State Lighting. International Conference on Multidisciplinary, Science, Engineering and Technology 2017, Bitlis, October 27–29, Turkey.

Eric, M. (1982). *Materials Science and Structural Physics Problems. 1st Edition*, Maket Publishing house, Istanbul.

Ertugral, H., Gunay, V. (2019). Conservation of Ahlat tombstones by using nanotechnology, *FEB-Fresenius Environmental Bulletin*, *28*(2), pp. 941.

Gevrek, A. I., Kazanci, N. (1994). Ignimbrite: Occurrence and properties (in Turkish), *Geological Engineering*, *38* (1991), pp. 39–42.

Hattatoglu, F., Bakis, A. (2017). Usability of ignimbrite powder in reactive powder concrete road pavement, *Road Materials and Pavement Design*, *18*(6), pp. 1448–1459, https://doi.org/10.1080/14680629.2016.1213182

Karaman, E. M., Kibici, Y. (2008). *Basic Principles of Geology, 2nd Edition*, Belen Publishing and Printing, Ankara.

Kuluozturk, M. F., Buyuksarac, A., Ozbey, F., Yalcin, S., Dogru, M. (2018). Determination of indoor radon gas levels in some buildings constructed with Ahlat stone in Ahlat/Bitlis, *International Journal of Environmental Science and Technology*, *16*(9), pp. 5033–5038, https://doi.org/10.1007/s13762-018-1692-0

Simsek, O., Erdal, M. (2004). Investigation of some mechanical and physical properties of the Ahlat stone (ignimbrite), *G.U. Journal of Science*, *17*(4), pp. 71–78.

Ozvan, A., Dincer, I. , Akin, M., Oyan, V., Tapan, M. (2015). Experimental studies on ignimbrite and the effect of lichens and capillarity on the deterioration of Seljuk Gravestones, *Engineering geology*, *185*, pp. 81–95, https://doi.org/10.1016/j.enggeo.2014.12.001

TS 500. (2000) *Requirements for design and construction of reinforced concrete structures*, Turkish Standards Institute, Ankara.

TS EN 12390-3. (2010) *Testing hardened concrete-Part 3: Compressive strength of test specimens*, Turkish Standards Institute, Ankara.

TS EN 12390-5. (2010). *Testing hardened concrete - Part 5: Flexural strength of test specimens*, Turkish Standards Institute, Ankara.

TS 25/T1. (2011). Natural pozzolan (Trass) for use in cement and concrete - Definitions, requirements and conformity criteria, Turkish Standards Institute, Ankara.

TS EN 1097-6. (2013). *Tests for mechanical and physical properties of aggregates - Part 6: Determination of particle density and water absorption*, Turkish Standards Institute, Ankara.

TS EN 1097-2. (2015). *Tests for mechanical and physical properties of aggregates- Part 2: Methods for the determination of resistance to fragmentation*, Turkish Standards Institute, Ankara.

Tunc, A. (2007) *Road Materials and Applications. 2nd Edition*, Nobel publishing, Istanbul.

Ulusoy, I., Cubukcu, H. E., Mouralis, D., Aydar, E. (2019). Nemrut Caldera and Eastern Anatolian Volcanoes: Fire in the Highlands, *Landscapes and Landforms of Turkey*, pp. 589–599, https://doi.org/10.1007/978-3-030-03515-0_35

Unsal, A., Sen, H. (2008). *Concrete paving blocks - Requirements and test methods TS 2824 EN 1338, Concrete and Concrete Materials Laboratory Experiments*, Department of Technical Research Materials Lab. Branch Office, Ankara.