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Fairy Chimneys of Cappadocia and Their Engineering Properties

[1]Alper Baba, [2]Abidin Kaya and [3]Necdet Turk
[1]Department of Geological Engineering, Canakkale Onsekiz Mart University, 17020, Canakkale, Turkey
[2]Department of Civil Engineering, Dokuz Eylul University, 35160, Tinaztepe, Izmir, Turkey
[3]Department of Geological Engineering, Dokuz Eylul University, 35100-Bornova, Izmir, Turkey

Abstract: The Cappadocia region of inner Anatolia has been focus of both historians and geologists due to its underground cities as well as fairy chimneys on the surface. The man-made structures were caved in soft tuffs more than 1500 years ago; thus, many researchers studied the mass properties of rackous materials in the region to evaluate as construction materials. In this study physical and chemical properties of spectacular structures, called fairy chimneys formed due to physicochemical reaction on the surface were investigated. Fairy chimneys are formed of a cap, a neck and a supporting body. Thus, samples were collected for both physical and chemical analyses of caps, necks and bodies of the fairy chimneys found in the Cappadocia region. Chemical analyses of fairy chimneys revealed that not only the chemical compositions of fairy chimneys are different from the background tuffous rocks but also the chemical composition of the fairy chimney parts, namely cap, neck and body. The chemical analysis of fairy chimney showed that cementation agents such as Fe_2O_3 and CaO play significant role on the development of fairy chimneys. Similar to the chemical composition variations, geotechnical properties of fairy chimneys also showed variations. For example, point load index of fairy chimneys in Bagli creek is higher than those of Pasabagi creek for both neck and body. Both chemical and mechanical analyses of fairy chimneys indicated that there is a positive correlation between the content of cementations elements and mechanical properties and size of the fairy chimneys.

Key words: Cappadocia, fairy chimneys, ignimbrite, tuff, pyroclastic materials

INTRODUCTION

Fairy chimneys, as called “Peribacalari” in Turkish, are spectacular futures of the Cappadocia region, located in the Central Anatolia, has been home to many civilizations since the Bronze age, whose influences are seen as numerous cave dwellings, churches, monasteries, hermitages and subsurface cities established into tuffaceous rocks in the lower of the Urgup formation, known as Kavak tuffs, during the early Christianity period. Some of these underground structures date at least 1500 years old. Thus, many historians continuously investigated the impact of these underground structures on civilization[1,2] whereas engineers studied the engineering properties of these extraordinary materials[3] for construction material purposes. For example, Topal and Doyuran[4], investigated the material and mass properties of the tuffs characterize engineering significance of tuffs. Yilmazer[5] investigated the engineering properties of the tuffs for possible construction of large underground structures following work of Erdogan[6,7]. Topal and Doyuran[8] also investigated geotechnical parameters of Kavak tuff and compared the obtained values with previously published values as well as the orientation of the major joints in the region to determine the factors governing engineering properties. The study by Topal and Doyuran[8] suggested that there are large variations in reported mass and material properties of tuff material found in the region. Furthermore, the authors showed that the joints developed in background rocks control the development of the fairy chimneys as well as their structural stability.

Nothing the high thermal isolation of underground structures, Unver and Agan[9] investigated heat conductance properties of the tuffs found in the region for food storage. The researchers showed that the tuff found in the region is superior to any other food storage system in terms of cost and long time durability.

Aydan and Ulusay[10] noted that previous studies mostly concentrated on tuffs found in Kavak area and launched a study both *in situ* and laboratory mass and material properties of tuff found in the Cappadocia region, namely Zelve tuffs and Urgup tuffs. Both laboratory and *in situ* test results revealed that there are large variations

Corresponding Author: Dr. Alper Baba, Department of Geological Engineering, Faculty of Engineering and Architecture, Canakkale Onsekiz Mart University, 17020, Canakkale, Turkey
Tel: +90 286 218 00 18 E-mail: alperbaba@comu.edu.tr

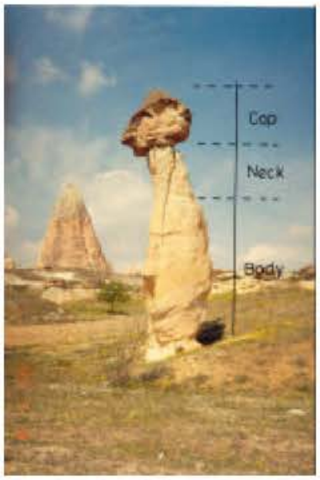

Fig. 1: Fairy chimney

Fig. 2: View of the fairy chimney in the study area

Fig. 3: Fairy chimney in Kavak Member

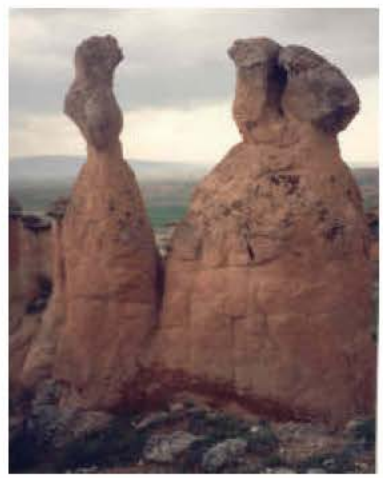

Fig. 4: Fairy chimney in Tahar Member

both *in situ* and laboratory engineering properties of tuffs found in the region. Furthermore Aydan and Ulusay[10] reported that there are also no significant variations in vertical and horizontal directions of engineering properties of the tuffs.

As it is stated above, one of the spectacular futures of the Cappadocia region is fairy chimneys. Fairy chimneys are uniquely-shaped earth-pillars of natural wonders, formed in pyroclastic deposits consisting of thick units of tuffs, volcanic ashes and ignimbrites. Goreme and Urgup are the best places to observe the development of the fairy chimneys where pyroclastic units are the thickest. These pyroclastic deposits were formed during the Plio- Pleistocene period and then subjected to considerable fluvial and aeolian erosion leading to the formation of the fairy chimneys. Figure 1 and 2 present typical fairy chimneys found in the area.

The fairy chimneys, as can be seen from Fig. 1, consist of a cap, a neck and a supporting body.

Although extensive studies have been conducted on mass and material properties of the tuffs found in the region; yet, no study has been conducted on the mass and material properties of fairy chimneys. Thus, the objective of this study is to determine the physical and mechanical properties of the cap, neck and body of the fairy chimneys found in the region to distinguish the factors affecting the development of these structures.

Geology of the region: The most recent detailed geological studies in the Cappadocia region were reported by Baba[11], Topal and Doyuran[8], Temel *et al.*[12], Aydan and Ulusay[10].

Thick and extensive deposits of the volcano-sedimentary sequence of the Urgup formation are found in the Cappadocia area. The Urgup formation consists of a Neogene sequence composed of tuffs, tuffite, ignimbrites, lahar, volcanic ash and marl intercalations. This formation is divided into the following volcano-sedimentary subunit members: Bayramhacili, Acidere, Kavak, Tahar, Karadag and Kisladag members.

The Kavak member is the predominant volcano-sedimentary unit consisting of ignimbritic tuffs, lahar, tuff and pumice fragments. Its best exposure is observed in Pasabagi, Cavusini, Goreme and Urgup areas. The Kavak member is approximately 80-90 m thick in the study area. The colour of the Kavak member changes from white to beige depending on the intensity of weathering and the original mineralogical composition. The bottom contact of the Kavak member is not exposed in the study area. The fairy chimneys are best developed in the Kavak and Tahar members of Urgup formation.

Rock masses forming the Kavak member were welded to each other with moderate to low welding degrees. Particularly, well-welded tuffs are situated in the area where topography is the highest. The welded zones are flattened, often forming glassy juvenile clasts called fiamme. Generally, fiammes develops within ignimbrites that demonstrate medium or welding. The thickness of ignimbrites in the area ranges from 1.5 to 5 m (used as building material for a long time). The low or medium grade welded ignimbrites form rounded hills and plains. So, the studied fairy chimneys are situated in these ignimbrites[11,13].

The Tahar member is massive and does not show flow layering. Phenocrysts of mica are found within the pyroclastic texture. Fairy chimneys are observed in the south of Pasabagi within this member. This member is mainly composed of pumice fragments. The size of the pumice fragments ranges between 1 and 10 cm and they are found as rounded or subrounded; however, locally angular pumice fragments can also be seen.

Fairy chimney types: Fairy chimneys in the Cappadocia area differ in shape and from one place to another. The distinct types of spectacular fairy chimneys are found in the Kavak and Tahar members. In general fairy chimneys consist of a cap, a neck and a body. Bodies of fairy chimneys in both the Kavak and Tahar members consist of tuff, tuffite, volcanic ash, pumice, non-welded to medium welded tuff units; however, the caps of fairy chimneys are formed by welded tuffs in the Kavak member whereas they are formed by lahar andesite and basalt in the Tahar member (Fig. 3 and 4).

The geomorphology of the area as well as the shape of the fairy chimneys indicate that both physical and chemical weathering are active in the region and these agents form different chimney types depending on which agent and to what extend dominant in the area. For example, various forms of erosion agents such as aeolian, fluvio-atmospheric and thermoclastic produce different reactions with rock masses depending on the lithological composition and structural characteristics, in turn, forming uniquely shaped fairy chimneys in the area. The caps of fairy chimneys are much more resistant to erosion than their bodies and necks. The caps are under the effect of aeolian and thermoclastic erosion whereas the necks are under the effects of winds and thermoclastic erosion.

Analyzing physicochemical properties of fairy chimneys

Chemical analysis: Samples were collected from the caps, necks and bodies of fairy chimneys in different parts of study area; For major element analysis as well as mineralogical and petrographical investigation. Samples were also collected from the areas where no chimneys exist to establish the chemical composition of the background. During sample collection, sometime it was not possible to take samples from neck and cap directly because fairy chimneys are as high as 20 m and under preservation. For such cases samples for caps, whenever the evidence was seen, were collected from the broken parts dropped nearby. The major element analyses of the samples were done by JSDX-100SY x-ray difractometer in Dokuz Eylul University.

Physical analysis: During field studies samples were also collected to determine the physical properties of the parts of fairy chimneys such as water content, unit weight, strength test as well as slake durability tests. The material properties such as unit weight, water content and unit weight were determined with accordance ASTM[14]. Point load index tests were carried out according to ISRM[15] and slake index test were carried out according to ISRM[16].

RESULTS

Chemical analysis: Mineralogical and petrographical studies indicated the tuff samples consisted of predominantly quartz, plagioclase, biotite and opaque minerals. Pumice and lithic fragments can be even seen with naked eye.

Major element analyses of the samples collected from fairy chimneys in Bagli Creek and Pasabagi both in Kavak member are presented in Table 1 and 2, respectively. It should be stated herein that there is a very susceptible zone (2-4 cm) made of fine to medium grains between cap and neck; thus, the chemical composition of this zone was also determined for the Pasabagi fairy chimneys in Avanos. 15 fairy chimneys were investigated in the study area.

Table 1: Major element analysis results of tuff samples from the fairy chimney in Bagli Creek in Kavak member

Oxide % sample	SiO_2	Al_2O_3	$\sum Fe_2O_3$	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	Loss of ignition
Background	66.23	15.39	3.11	1.06	3.09	2.93	3.52	0.35	0.08	4.29
Cap	69.62	14.49	1.59	0.37	2.57	2.58	4.18	0.20	0.05	4.11
Body	66.52	16.59	2.58	0.48	4.17	3.31	3.25	0.29	0.04	2.56

Table 2:Major element analysis results of tuff samples from a fairy chimney in Pasabagi in Kavak member.

Oxide % sample	SiO_2	Al_2O_3	$\sum Fe_2O_3$	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	Loss of ignition
Cap	67.67	14.79	1.89	0.90	2.05	2.35	3.31	0.23	0.04	5.94
Zone between cap and neck (2-4 cm)	59.63	20.35	2.43	2.01	2.10	1.05	1.25	0.44	0.01	10.91
Neck	70.84	13.59	1.27	0.18	1.48	1.89	5.18	0.17	0.07	5.28
Body	70.05	13.74	1.82	0.64	2.57	2.49	4.19	0.20	0.07	4.53

Table 3: Physical properties of fairy chimneys

Type of rock			Unit weight					
Sample location		Fairy chimney	Dry (kN/m³)	Saturated (kN/m³)	Porosity n (%)	Water content w (%)	Void ratio (e)	Specific gravity (Gs)
Kavak Member	Pasabagi	Cap	8.60	12.1	35.9	41.2	56.1	2.17
		Neck	16.6	19.2	25.9	15.6	34.9	2.24
		Body	15.3	18.5	32.5	21.2	48.1	2.27
	Bagli Creek	Cap	16.1	19.0	29.6	18.3	42.0	2.29
		Body	19.0	20.6	16.7	8.8	20.1	2.28
	Catalkaya	Cap	12.9	17.0	41.0	31.7	69.6	2.20
		Body	15.0	18.4	33.9	22.5	51.3	2.28
Tahar Member		Body	15.0	18.5	35.0	23.4	53.9	2.31

Table 4: The point load index of the tuff samples taken from different locations

	Kavak member			
Sample	Catalkaya (Mpa)	Pasabagi (Mpa)	Bagli creek (Mpa)	Tahar member (MPa)
Cap	0.25	0.10	0.41	-
Neck	-	0.08	-	-
Body	0.22	0.23	0.30	0.11

Table 5: The Uniaxial Compressive strength of the tuff samples taken from different locations

		Uniaxial compressive strength (Mpa)	
Sample location	Member	Dry	Saturated
Pasabagi area			
	Kavak	1.97	1.65
Espelli district		7.76	6.64
White tuff		9.74	7.40
Pasabagi area	Tahar	3.99	2.47

Table 6: Comparison of chemical composition of the Kavak Member

	Temel *et al*, (1998)		This Study			
	Rim	Core	Core	Background	Cap	Body
K_2O	0.56	0.70	0.51	3.52	4.18	3.25
CaO	7.51	6.76	8.12	3.09	2.57	4.17
FeO_t	0.24	0.13	0.16	3.11	1.59	2.58
Na_2O	6.53	7.12	6.55	2.93	2.58	3.31
SiO_2	58.46	61.25	58.98	66.23	69.62	66.52
Al_2O_3	25.07	24.96	26.01	15.39	14.49	16.59

Physical analyses: Table 3 presents the water content, unit weight, porosity, void ratio and specific gravity of the samples collected from different locations of fairy chimney parts. The average of the dry and saturated unit weights of the cap in the Pasabagi area, out of 15 samples, are 8.6 kN m^{-3} and 12.1 kN m^{-3}, respectively. These values are very low compared to the neck and body unit weight of other fairy chimneys (Table 3). Porosity, water content and void ratio of the fairy chimney caps are found to be more than those of their bodies and necks. Note that unit weights, porosities and specific gravities of the Kavak member and the Tahar member are approximately the same. However, there are differences in the physical properties of the Kavak member reflecting the changes in chemical composition within the member.

Point load index tests and uniaxial strength tests: The results of point load index (Is) values for the fairy chimney samples taken from around Urgup and Goreme sites are presented in Table 4. The rocks are classified as weak based on the obtained values since ISRM considers the rocks with less than 1 MPa is weak. Table 5 presents the uniaxial strength of the rocks in the Urgup area. Note that the uniaxial strength of rocks especially in the Espelli district and white tuffs, are much higher than those of the Pasabagi area. The rocks in Urgup area are traditionally used as construction materials due to their relatively high strength; thus, fairy chimneys are not well developed in this area. Table 5 also indicates that the fairy chimneys are well developed in the Pasabagi area where the rocks have low uniaxial strength (<10 MPa).

Slake durability index (I_d): Three-cycle slake durability index was performed with accordance to ISRM[16] to determine the weakening and disintegration of the tuff samples. The relations between the slake durability index versus the number of cycles of different parts of the fairy chimneys are presented in Fig. 5. The results indicate that

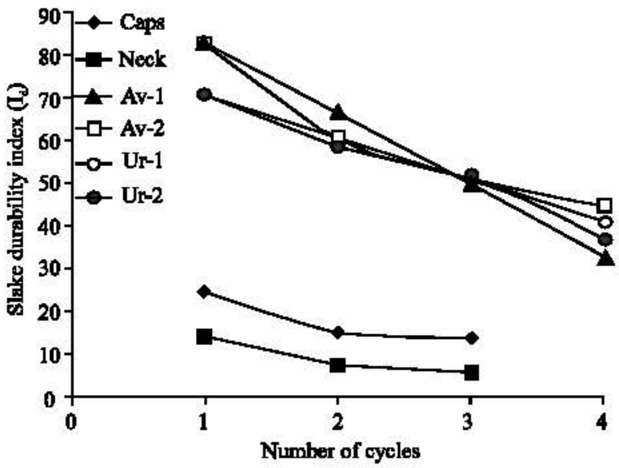

Fig. 5: Comparison of the slake durability index of block samples cut from intact tuff in Avanos and Urgup area with those of parts of fairy chimneys in Pasabagi

Fig. 6: The narrowest part of the fairy chimneys

all parts of fairy chimneys have very low slake durability (I_d<30) according to the classification[17]. However, the necks and bodies of the fairy chimneys have lower slake durability index than their caps. Again, from slake durability index values, it is seen that bodies and necks of the fairy chimney are more erodable than the caps. This is because the caps are made of welded tuffs whereas neither necks nor bodies are made of welded tuffs.

DISCUSSION

Chemical composition: Temel *et al.*[12] was first to investigate the chemical composition of geological members in the Cappadocia region. Table 6 compares the chemical composition of the Kavak member reported by Temel *et al.*[12] and finding of study. Table 6 indicates that there might be significant variations in the chemical composition of background tuffs and fairy chimneys formed in these tuffs. For example, Temel *et al.*[12] reported that SiO_2 content of the Kavak member ranges between 58.46 to 61.25%, Fe_2O_3 content ranges between 0.13 to 0.24% and Al_2O_3 ranges between 24.96 and 26.01%. However, both SiO_2 and Fe_2O_3 contents of fairy chimneys in the Bagli Creek and Pasabagi areas are higher, whereas Al_2O_3 is lower than those of reported by Temel *et al.*[12]. Such comparison in chemical composition indicates the significance of cementation between particles, which controls the rate of erosion. For example, the chemical composition of thin zone between cap and neck (2 to 4 cm) is closer to that of background. This zone is also narrowest part of the fairy chimneys in Pasabagi (Fig. 6). Also, note that the loss of ignation is highest in this thin zone, indicating that the particles in this zone are weakly cemented.

Mechanical properties: Figure 5 compares the slake durability index of block samples cut from intact tuff in Avonos and Urgup area with those of parts of fairy chimneys in Pasabagi (Kavak member). Figure 5 clearly indicates that slake durability of tuffs decreases by 60% after four cycles. Considering those parts of fairy chimneys have been subjected to previous freezing-thawing cycles, the parts of fairy chimney are more durable than background tuff. This indicates the importance of the chemical composition and cementation of particles.

It is know that strength of a material is a function of its chemical composition and this is not exception to fairy chimneys. When point load indexes of fairy chimneys in the Pasabagi and Bagli Creek areas are compared, the effect of chemical composition on the strength of fairy chimneys is seen. Note that point load indexes of fairy chimneys in Bagli creek are higher than those of Pasabagi creek for both neck and body. Note that, for example, both Fe_2O_3 and CaO contents of fairy chimneys in the Bagli creek area are higher than those of fairy chimneys in the Pasabagi area. Thus, variation in strength of fairy chimneys might be explained with variations in their chemical composition such as Fe_2O_3 and CaO that are good cementing agents between particles. Chemical composition is a primary factor controlling the development, size and durability of the fairy chimneys in the Cappadocia region. Knowing that each fairy chimney is uniquely shaped and subject to different erosion agent such as aeolian and thermoclastic, it is necessary to determine the effect of each of these agents on the shape of fairy chimneys.

REFERENCES

1. Dam, R.V., 2000. Kingdom of Snow: Roman Rule and Greek Culture in Cappadocia, University of Pennsylvania Press, USA.
2. Kostot, S., 1978. Caves of God: The Monastic Environment of Byzantine Cappadocia, MIT Press, USA.
3. Erdogan, M. and E. Yüzer, 1994. Variation of physical and mechanical behavoirs of volcanic rocks in Cappodocia as a function of temperature. Seventh Int. Conf. Eng. Geol., 5-9 September, Lizbon, pp: 1001-1006.
4. Topal, T. and V. Doyuran, 1995. Effect of discontinuities on the development of fairy chimneys in the cappadocia region. Turk J. Earth Sci., Ankara, 4: 49-54.
5. Yilmazer, I., 1995. Engineering geologic factors in the design of a large underground structure in a tuff sequence in cappadocia. Eng. Geol., pp: 235-241.
6. Erdogan, M., 1986. Nevsehir-urgup yoresel tuflerinin malzeme acisindan arastirilmasi. Ph.D. Thesis, Istanbul Technical University.
7. Erdogan, M., 1989. Nevsehir tuflerinin hafif yapi gereci olarak degerlendirme olanaklarinin Arastirilmasi. Muhendislik Jeolojisi Bulteni, 11: 75-82.
8. Topal, T. and V. Doyuran, 1997, Engineering geological properties and durability assessment of the Cappadocia Tuff. Eng. Geol., pp: 175-187.
9. Unver, B. and C. Agan, 2003. Application of heat transfer analysis for frozen food storage caverns. Tunneling and Underground Space Technology, pp: 7-17.
10. Aydan, O. and R. Ulusay, 2003. Geotechnical and geoenvironmental characteristics of man-made underground structures in Cappadocia, Turkey. Eng. Geol., 245-272.
11. Baba, A., 1995. Engineering geology of Urgup-goreme tuff. M.Sc Thesis, Dokuz Eylul University, Graduate School of Applied Sciences, Izmir.
12. Temel, A., M.N. Gundogdu, A.Gourgaud and J-L. Le Pennec, 1998. Ignimbrites of Cappadocia (Central Anatolia, Turkey): Petrol. Geochem., J. Valconol. Geothermal Res., pp: 447-471.
13. Baba, A. and N. Turk, 1995. Engineering Geological Aspects of Fairy Chimneys Formation in Urgup Area, IESCA, 1-2, Izmir.
14. ASTM-D 4555-90, 1995. Standard Test Method for Determining Deformability and Strength of Weak Rocks by an *in situ* Uniaxial Compressive Test. American Society of the Text Material, ASTM-D 4555-90.
15. ISRM., 1984. Suggested Method for Determining Point Load Strength. ISRM, Point Load Test, Received 10 June, pp: 50-53.
16. ISRM., 1979. Suggested methods for determining water content, porosity, density, absorption and related properties and swelling and slake-durability index properties. Intl. Rock Mech. Min. Sci and Geocmech. Abstr., 16: 141-156.
17. Anonymous, 1977. The description of rock masses for engineering purposes. Q.Jl. Eng. Geo., 3: 1-24.