CHEMICAL AND MINERALOGICAL COMPOSITIONS OF PERSIAN TRADITIONAL ADOBE BRICKS

CHEMISCHE UND MINERALOGISCHE ZUSAMMENSETZUNGEN VON PERSISCHEN TRADITIONELLEN LEHMZIEGELN

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SUMMARY

The objective of this paper is to compare the chemical and mineralogical compositions of Persian adobes. For this reason, XRF and XRD analyses are performed on two historical and one new adobe sample and results are compared with available data in the literature. Obtained results indicate the presence of similar chemical and mineralogical compositions in the tested adobe samples.

ZUSAMMENFASSUNG

Das Ziel dieser Arbeit ist es, die chemische und mineralogische Zusammensetzungen persischer Lehmziegel zu vergleichen. Aus diesem Grund werden Röntgenfluoreszenz-Analyse und Röntgendiffraktometrie an zwei historischen und einem neuen Lehmziegel durchgeführt und die Ergebnisse mit verfügbaren Daten in der Literatur verglichen. Die erhaltenen Ergebnisse weisen auf das Vorhandensein ähnlicher chemischer und mineralogischer Zusammensetzungen in den getesteten Lehmziegeln hin.

1. INTRODUCTION

Adobe bricks are made of clay earth containing 30% to 40% clay and 60% to 70% earth mixed with water. In some cases, in order to prevent the adobe from cracking during drying or to increase its tensile strength, enhance its thermal insulation or reduce the weight, fibrous materials are added to mixture. Fibrous materials include different materials such as straw or the droppings of herbivores such as goats, cows, horses and camels. Adobe or mud bricks can be made simply by forming the mixture and leaving them to dry under the sun. Water is added to clay and earth, and it is left for one or two days to let the earth mixture soak in water to activate the clay. Then it is mixed by a shove, or by feet, and then by hands. The mud is then forged to moulds. After one or two days, the adobe bricks are placed vertically for faster drying. The dry adobe bricks are collected together to be used. Adobe materials and buildings have been used throughout the world since ancient times. Adobe buildings are still used in many parts of the world. Adobe buildings, in particular historical ones, need permanent maintenance and restoration. In restoration works, compatible materials from the viewpoints of chemical, physical, mechanical, rheological and thermal characteristics must be used in order to keep the authenticity and original functioning of the building [1]. For this reason, careful characterization of original and new materials must be done in order to select the right materials, historical or new, for repair and restoration.

A number of researchers have studied the properties of Persian adobe bricks. In 2018, Hosseini et al. [2] conducted mineralogical and physical tests on two historical and two new adobe samples from Belqeis castle in Esfarayen, North-east Iran. Results showed that mainly calcite and quartz occurred, indicating lack of clay minerals. In addition, a major part of minerals consisted of silicates (muscovite, biotite, feldspar and enstatite).

In 2019, Zakavi [3] studied the soil from six mining pits near the Choga Zambil in Susa, South-east Iran, for making new adobe bricks. Calcite and quartz were the dominant minerals in soil samples. The soil samples were poor in terms of high quality clay minerals such as kaolinite and montmorillonite. The amount of chlorine and sulphate ions in four soil samples were high. Soil samples contained sodium and potassium chloride showed a higher potential for swelling of clay.

In 2020, Dormohamadi and Rahimnia [4] studied the dynamic compaction on the mechanical behaviour of adobe bricks made with six different clayey-silty soil types from six different mines in the town of Ardakan near Yazd, Central Iran.

The experiments included the determination of physical, mineralogical and chemical characterization as well as mechanical properties tests. Results showed that the main component of all six soil samples was as a mixture of silicates and calcium aluminates (feldspar). In all of them, the amount of silica was approximately one-third of the weight of the soil. This is due to the high amount of aeolian sand in this desert region of Iran. Four main phases of mineralogical composition, i.e. quartz, calcite, feldspars, and clay minerals, as well as traces of dolomite were present in all soil types. The amount of swelling clay minerals like smectite in the soil was low.

In 2021, Eskandari [5] studied the physical, mineralogical and mechanical properties of Persian historical and new adobe bricks. Six groups of adobe bricks, consisting of three groups of historical adobe bricks from the town of Maybod near Yazd and from the town of Jarquyeh near Isfahan, and three groups of new adobe bricks from Maybod and from Yazd, Central Iran, were tested. Mineralogical results showed that quartz was a significant amount of constituent minerals. These results are also consistent with the geological characteristics of soil formation in the desert areas of the studied adobe bricks and the presence of abundant windblown sand in those areas. Calcite was the second most abundant mineral in the soil of each study group, which is due to the characteristics of arid and semi-arid regions. Albite was the third most abundant mineral among the studied adobe bricks groups, which provides a relatively good resistance to adobe bricks.

In this work, the properties of historical and new Persian mud bricks were determined by XRF and XRD analyses. A comparison was made with available data from other researchers. The obtained results enhance the information about Persian adobe bricks.

2. STUDIED ADOBE BRICKS

Adobe bricks for testing were taken from different adobe buildings in the town of Maybod, 55 km east of the city of Yazd, Central Iran. Adobe bricks tested are coded as A4 made in 2017 in the Narin castle used for recent restorations, C1 made in 1870 in the Kazem Abad village as an original and historical adobe brick, and D2 made in 1320 in the Narin castle as an original and historical adobe brick.

The results of the current study were compared with former surveys, described in the previous section. All adobe samples studied are shown in Table 1.

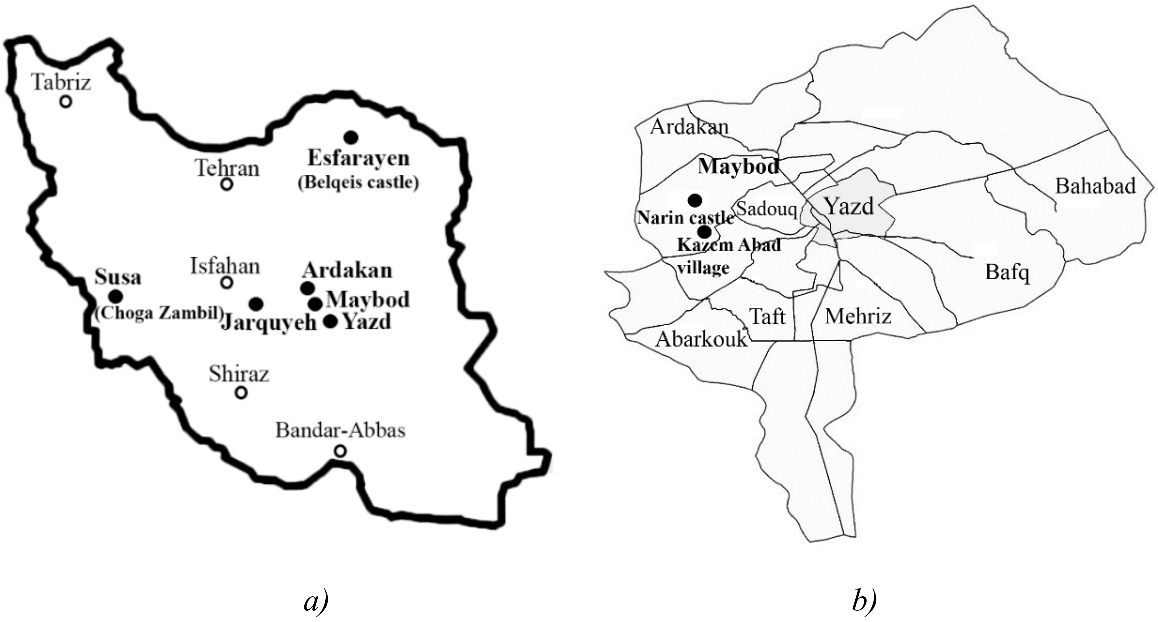

Fig. 1: Locations of studied adobe samples: a) by other researchers (Yazd, Maybod, Ardakan, Esfarayen, Jarquyeh and Susa), b) in this study (Narin castle and Kazem Abad village in Maybod)

Table 1: Adobe samples studied in this study and by other researchers

Code	Location	Era	Reference
This study			
A4	Narin castle (Maybod)	2017	-
C1	Kazem Abad village (Maybod)	Probably 1870	-
D2	Narin castle (Maybod)	Probably 1320	-
Other researchers			
K1	Ardakan (60 km east of Yazd)	2016	[4]
K2	Jarquyeh (270 km east of Yazd)	Probably 1900	[5]
K3	Yazd	2019	[5]
K4, K5	Belqeis castle (Esfarayen, North-east Iran)	Probably 1300	[2]
K6, K7	Belqeis castle (Esfarayen, North-east Iran)	2016	[2]
K8, K9	Choga Zambil (Susa, South-east Iran)	2016	[3]

3. XRF ANALYSIS

The chemical composition of the soil samples was determined by XRF – analysis, using a Bruker AXS S4 Pioneer spectrometer with Rh – radiation. Melting tablets were prepared and the loss on ignition (1000°C) was determined. Major and some trace elements have been analyzed. Table 2 shows the results of XRF investigations for clay samples in this study and by other researchers. In the clay samples from Maybod, 55 km from Yazd, investigated in this study, SiO_2, CaO and Al_2O_3 are the dominant chemical compounds. In addition, Ba, Sr and Zr are common trace elements in all samples. The historical and new clay samples investigated in this study have a relatively similar chemical element composition. The locations of the different samples are only a few kilometres apart.

Adobe samples K1 [4] taken from Ardakan, 5 km from Maybod and 60 km from Yazd, have a similar chemical composition. The dominant compounds are SiO_2, CaO, Al_2O_3, and MgO. The amount of loss on ignition is also comparable. The similarity of the samples in Ardakan and Maybod is due to the comparable soil, as these two towns are only 5 km apart.

In clay sample K9 [3], the order of abundance of chemical elements is the same, dominated by SiO_2, CaO, Al_2O_3 and MgO. The loss on ignition, on the other hand, is significantly higher and the high CaO content of the sample suggests a higher carbonate content. This new adobe sample was produced in Susa, about 900 km from Maybod.

Table 2: Main element composition as oxides obtained from the XRF investigation of adobe samples in this study and by other researchers (percentage of weight, w-%))

Oxides	**Adobe Type**									
	This Study			**Other Researchers**						
	Location									
	Maybod			**Ardakan**						**Susa**
	A4	**C1**	**D2**	**K1 [4]**						**K9 [3]**
				Sample: 1	**2**	**3**	**4**	**5**	**6**	
SiO_2	45.18	45.16	46.11	39	41	44.9	42.2	43.7	43.3	33.1
TiO_2	0.54	0.53	0.52	0.7	0.6	0.7	0.6	0.7	0.6	0.65
Al_2O_3	10.33	8.94	9.75	10.7	9.8	10.8	8.5	12.4	10.6	7.51
Fe_2O_3	4.52	3.85	4.10	3.6	3	3.6	3.2	4.3	3	4.35
MnO	0.09	0.09	0.09	-	-	-	-	0.1	-	0.07
MgO	4.34	4.09	4.31	5.7	6.6	6.8	6.3	5.6	5.6	5.77
CaO	16.31	18.20	16.61	15.7	13.3	12.9	17.8	14.3	14.3	22.07
K_2O	2.12	1.88	1.91	2.7	2.5	2.8	2.4	2.9	2.5	1.84
Na_2O	1.28	1.33	1.43	1.5	2.6	1.4	1	1.3	2	0.53
P_2O_5	0.14	0.13	0.14	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.14
L.O.I	17.68	17.10	17.35	18.3	18.3	15.9	17.8	14.6	17	23.49
Sum	102.54	101.29	99.93	97.0	97.7	99.8	99.8	99.9	98.9	99.52

4. XRD ANALYSIS

The mineralogical composition of the adobe samples was determined by X-ray diffraction using a Bruker AXS D8 – Advance X-ray diffractometer with Cu anode, operating at 40 kV – 30 mA, a step size = 0,01° and a scanning range 2θ between 5°-70°. Fig. 2 shows the XRD pattern for adobe brick A4. Table 3 presents the mineralogical compositions identified by XRD for adobe samples in this study and by literature. In general, most compounds found in adobe samples studied in this research are similar. The common compounds in all samples include quartz (SiO_2), different feldspars like albite ($Na(AlSi_3O_8)$)–and orthoclase ($(K_{0.94}Na_{0.06})(AlSi_3o_8)$). Furthermore, calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$) and different clay minerals, clinochlore-1Mllb ($Mg_5Al(Si, Al)_4O_{10}$) and illite ($K(Al_4Si_2O_9(OH)_3)$) are present in all samples. Hematite, (Fe_2O_3) also exits in the samples except in adobe sample C1, made in 1870.

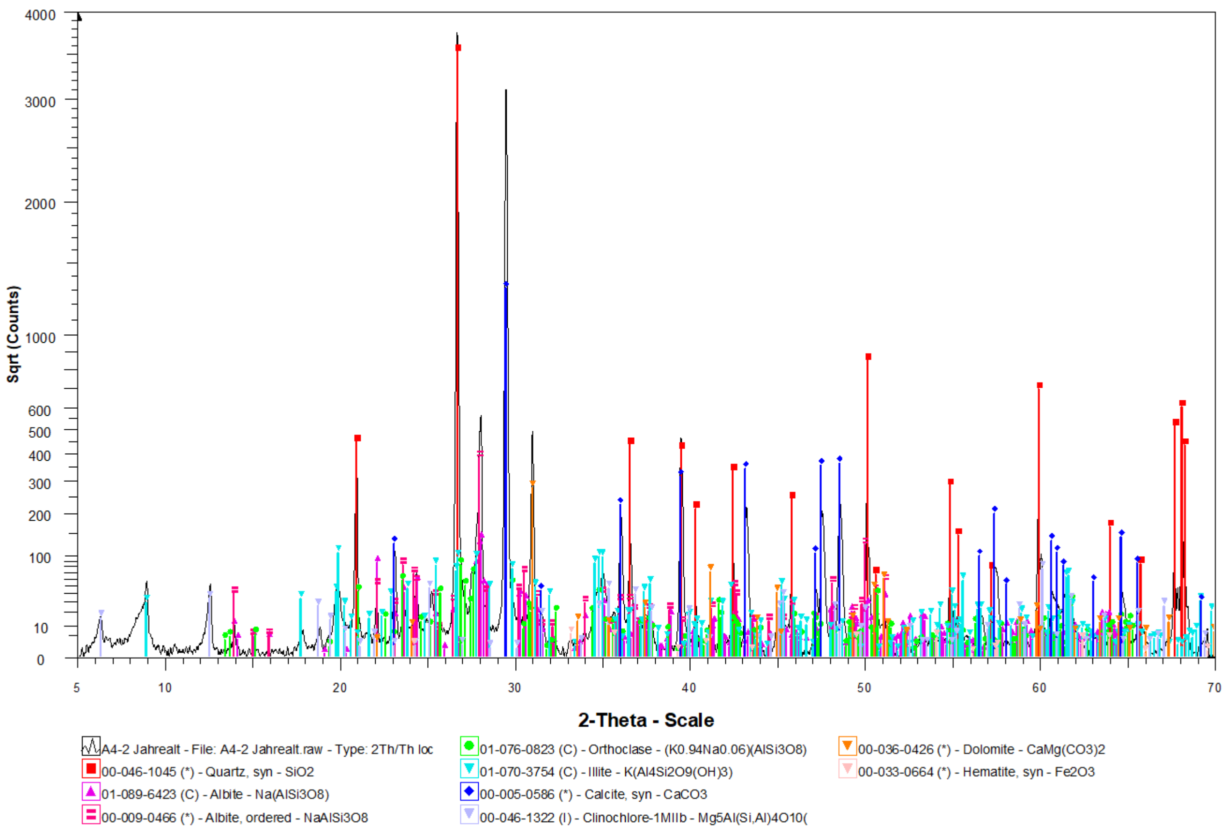

Fig. 2: XRD pattern for adobe brick A4

In historical adobe samples, C1 made in 1870 and D2 made in 1320, additional compounds exist. Palygorskite ($Mg_5(Si\ Al)_8O_{20}(OH)_{2.8}$) is observed in both adobe samples C1 and D2. Adobe sample C1 contains ferroactinolite ($(Ca,Na,K)_2Fe_5Si_8O_{22}$), while D2 contains cordierite ($Mg_2Al_4Si_5O_{18}$) and heulandite ($(X)_3(Al_3Si_9O_{24})$*7-8H_2O). In all studied samples, swelling clay minerals like montmorillonite and smectite are absent, but the non-swelling clay mineral illite is present. The absence of swelling clay minerals is important for producing good quality adobe bricks. Swelling clay minerals give problems of fissuring due to shrinkage during desiccation. The presence of quartz is expected as a typical component of soil in the desert of the region.

Adobe sample K2 [5], made in 1900 in Jarquyeh 270 km east of Yazd, and adobe sample K3 [5], made in 2019 in Yazd, show the greatest similarity in mineral content. They contain quartz (SiO_2), albite ($NaAlSi_3O_8$), calcite ($CaCO_3$), clinochlore-1Mllb ($Mg_5Al(Si,\ Al)_4O_{10}$), and dolomite ($CaMg(CO_3)_2$). Other adobe samples from other locations have a completely different mineralogical composition; the reason is the different types of soils at different locations far from each other. The XRD results show that quartz and calcite are present in all clay samples of Table 3 except clay sample K5.

In addition, XRF results in Table 2 show a comparable chemical composition to adobe samples of type K1 from Dormohamadi and Rahimnia [4]. Adobe samples of the series K1 in Table 2 are made in Ardakan with the same soil used for adobe samples studied in this research, while the K9 adobe sample with significantly lower concentrations of SiO_2 and Al_2O_3 but higher contents of CaO was made in Susa, very far from Ardakan.

Table 3: Mineralogical composition obtained from the XRD test for adobe samples in this study and by other researchers

Compound Name	**Adobe Type**											
	This Study			**Other Researchers**								
	Location											
	Maybod			**Ar-da-kan**	**Jarquyeh**	**Yazd**	**Esfarayen**				**Susa**	
	A4	**C1**	**D2**	**K1**	**K2**	**K3**	**K4**	**K5**	**K6**	**K7**	**K8**	**K9**
				[4]	**[5]**		**[2]**				**[3]**	
Quartz	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Albite	✓	✓	✓					✓	✓	✓		
Albite, ordered	✓	✓	✓		✓	✓						
Orthoclase	✓	✓	✓									
Calcite	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Clinochlore-1Mllb	✓	✓	✓		✓	✓						✓
Dolomite	✓	✓	✓	✓	✓	✓					✓	
Illite	✓	✓	✓	✓								
Hematite	✓		✓									
Palygorskite		✓	✓									
Ferroactinolite		✓										
Cordierite			✓									
Heulandite			✓									
Hydrotalcite												
Feldspar				✓							✓	
Kaolinite				✓								
Chlorite				✓								
Smectite				✓								
Muscovite					✓	✓	✓	✓	✓	✓		
Microcline						✓						
Biotite							✓					
Enstatite								✓		✓		
Apatite								✓	✓	✓		
Gypsum												✓

5. CONCLUSION

This study focused on XRF and XRD analyses of Persian historical and new adobe bricks. Samples were taken from historical buildings and the new adobe bricks were used in the same places for restoration. Historical buildings are a few kilometres apart all located in the city of Maybod, 55 km east of the city of Yazd, Central Iran.

According to obtained results from XRF analysis, a similar chemical composition exists in the studied adobe samples, be historical or new. The dominant chemical compounds are SiO_2 with about 45 w-%, followed by CaO and Al_2O. The high similarity of chemical composition in the samples can be related to the same type of soil in this area. The chemical trace elements with higher amounts are respectively Ba, then Sr and Zr.

XRD results indicate that all samples studied have a similar mineralogical composition. The common phases in all samples are quartz, feldspars (albite and orthoclase), calcite, dolomite and clay minerals (clinochlore and illite). Other phases are also observed in some samples. Clay minerals with a high swelling potential like montmorillonite and smectite are absent in the studied samples, whereas the non-swelling clay mineral illite is present.

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