academicJournals

Vol. 11(17), pp. 217-224, 16 September, 2016
DOI: 10.5897/IJPS2016.4505
Article Number: 5FA907460492
ISSN 1992 - 1950

http://www.academicjournals.org/IJPS

International Journal of Physical Sciences

Full Length Research Paper

Characterisation of mortars from the Ottoman period in Algiers (Algeria) through their physical and chemical properties

Naima Abderrahim Mahindad* and Messaoud Hamiane

[1]Research Unit Materials, Processes and Environment (Ex LMMC), Department of Materials Engineering, Faculties of Engineering, University of M'Hamed Bougarra, Boumerdes, Algeria.

Received 8 May, 2016; Accepted 22 August, 2016

In traditional and historical Algerian architecture, one can find a series of mortars that were used for grouting and coating masonry. Although Algeria has a very rich heritage park, our interest mainly focuses on the mortars used in buildings from the Ottoman period, in Algiers and in particular, the mortars of the Citadel of Algiers, the Casbah and villa Mahieddine. This study allows us to determine the physical properties of a selection of mortars and identify their chemical and mineralogical composition. The chemical and mineralogical analyses showed that the studied mortars of the Ottoman period in Algiers contain raw materials in their composition, namely sand, lime, crushed brick and a few additions, such as natural adjuvant. These mortars are made according to specific proportions of binder (lime) and aggregates (sand). For jointing mortars, the proportion is one-part lime to one and a half to two parts sand (1 to 1.5 - 2), whereas for finishing mortars, it is one-part lime for two to three parts sand (1 to 2-3). The physical characteristics show significant porosity and absorption percentages for most of the mortar samples, with exception to MJ4 jointing mortar samples, taken from Villa Mahieddine and MC1 coating mortar samples, taken from the Powder House and Villa Mahieddine, where the percentages did not exceed 15% of water absorption and 27% porosity, respectively. Furthermore, the chemical analysis of the samples showed increased levels of the following oxides SiO2, Al2O3 and Fe2O3, which confirm the hydraulic nature of the mortars.

Key words: Algiers, characterisation, chemical and mineralogical composition, lime mortars, physical properties.

INTRODUCTION

Knowing the characteristics of materials, is an important source of information for understanding the historical and archaeological evolution of mortars, and towards finding a mortar with the characteristics similar to old mortar, which can then be used in the restoration of historical monuments.

The issue concerning the preparation of mortars for restoration purposes has become increasingly important

*Corresponding author. Email: mahindadnaima@gmail.com Tel: 00213 555-025-627.

over the last decade. Mortars intended for the restoration of historic buildings must be compatible with the characteristics of the materials onto which they are to be applied or those that they are intended to replace (Rota Rossi, 1986). It is important that the mortar used during restoration and/or reconstruction operations, has the same morphological and physical characteristics, so that the new mortar does not differ too much from the old one (Ashurst, 1983).

Old mortar, in particular "Roman concrete" is the mortar of reference that has been in use since ancient times until today (Mallinowski, 1982). It has been used for the conservation of heritage objects (Büttner and Prigen, 2007). This mortar uses lime as a binding agent and is characterized for its great plasticity (Kurugöl and Güleç, 2015).

In recent decades, research on masonry binders has essentially focused on the characterisation of the materials used in historic buildings (Palazzo-Bertholon, 1998; Coutelas, 2003; Binici et al., 2010). This new line of research opened a sphere towards new knowledge and perception of materials, through a scientific and analytical approach.

In the case of Algeria, studies relating to lime mortar are extremely rare and cover only a portion of its historical and archaeological heritage: Mortars of the Ottoman period in Algeria were studied through an unpublished literature exploited in the works of Chergui (2007) and that of Foufa (2010), and which consist of the Ottoman period archives. This first-hand documentation enables us to identify the different materials used at the time, as well as the construction techniques and their implementation, which reveals to us all of the local knowledge and mastery of the builders of that time. These studies were supported by works undertaken on the characterisation of mortars, which tell us about the composition of the same and their evolution (Boukhenouf, 2006; Belaidi, 2011, Ait ouakli, 2010). In addition to recent works on mortars of the Ottoman period in Algiers, proposing mortar preparations in order to find the compositions that are a closest match to old mortars and are thus compatible with them (Hamiane et al., 2010).

The mortar could be used for several purposes, such as, filling, grouting or coating. Whatever its use, the base components are the same: These mortars consist of sand and lime, to which have been added other components, such as the broken tiles or crushed bricks and in some cases, broken stone (Chergui, 2007). Other historic sources show evidence that the mortar of the Ottoman period consisted of lime and red clay or red sand, which were more or less clay-like (Lespès, 1930; Rozet, 1830).

The aim of this study is to characterise of ancient lime based mortars, used in previously selected Ottoman constructions and to identify their chemical and mineralogical composition, as well as its production techniques. The results obtained are compared to various historical studies.

In view of the diversity of Ottoman buildings, as regards their use and geographical location, we have limited our research to the most representative buildings, as regards their function and geographic location, in order to target a more comprehensive sampling of the mortars used during this period. The buildings selected as part of this study are:

1) The Citadel of Algiers: it is the pillar of Ottoman power, which consists of various structures, such as a palace and the mosque of Dey, Beys Palace, the Summer Pavilion, Hammam of Dey, the Janissaries quarter, the Skifa [a monumental door], pillboxes (The casemates) and the powder house. All of the above were built between the sixteenth and eighteenth centuries. Within this palatial complex, we have chosen two buildings from these samples, the powder house and the Casemates (The pillboxes). The two buildings show some deterioration in their masonry and in particular, in the coatings.

2) The Casbah of Algiers: The Medina, which constitutes the Ottoman city, contains most of the houses and dwellings of that time. These houses were built between the sixteenth and eighteenth centuries. Samples mortars studied of the Casbah of Algiers were taken from one of its houses. Most of the latter are in an advanced state of degradation. Their masonry has been considerably damaged.

3) Villa Mahieddine: This is a Fahs house (a house in the countryside). This villa was mostly used during the summer; it was built between the sixteenth and seventeenth century. It is a building that is in a better state of conservation than the other buildings and it shows very few signs of deterioration in the masonry and coatings. All samples studied are located in Figure 1.

METHODOLOGY

Materials

Mortar can have series of uses, such as jointing mortars for masonry, finishing mortar, coating and waterproofing for the terrace. In this study, we chose eight (08) samples of grouting and coating, found at the above listed sites. These mortars show the visual changes as regards their colours and textures.

Jointing mortars

All samples of jointing mortars studied are presented in Figure 2.

a) The Citadel of Algiers: We have chosen two samples of jointing mortar:

i) The powder house (MJ1): Is a yellowish mortar (yellow beige), with a large quantity of scattered lime particles of a more or less significant size. It also contains grains of gravel, but in minute quantities. When handled, this is a brittle material, but which has eroded, the resulting particles of which have a heterogeneous particle size (Figure 2a).

Figure 1. Location of samples. a/b: Site of samples MJ1 and MC1: Powder keg; c/d: Site of samples MJ2 and MC2: Casemates; e/f: Site of samples MJ3 and MC3: Casbah of Algiers; g/h: Site of samples MJ4 and MC4: Villa Mahieddine.

ii) The Casemates (The pillboxes) (MJ2): This is an orange-coloured mortar, highly compact in appearance but which crumbles to the touch. Eroded, it consists of very fine red sand particles and dirt and shows the presence of whitish traces of lime in a very reduced amount, however the other components are not noticeable (Figure 2b).

b) The Casbah (MJ3): This is an orange coloured mortar, highly compact in appearance but brittle to the touch. Eroded, it consists of very fine sand particles and dirt and shows the presence of whitish lime particles of lime of various sizes. With a naked eye, one can also easily see a given number of pores and grains of a larger grain size in a reddish-brown colour (Figure 2c).

c) The villa Mahieddine (MJ4): This is a bright orange coloured mortar, very compact in appearance but brittle to the touch. It has some dark spots (in very reduced quantities) and small-sized lime grains. Eroded, it consists of very fine particles of sand and clay (Figure 2d).

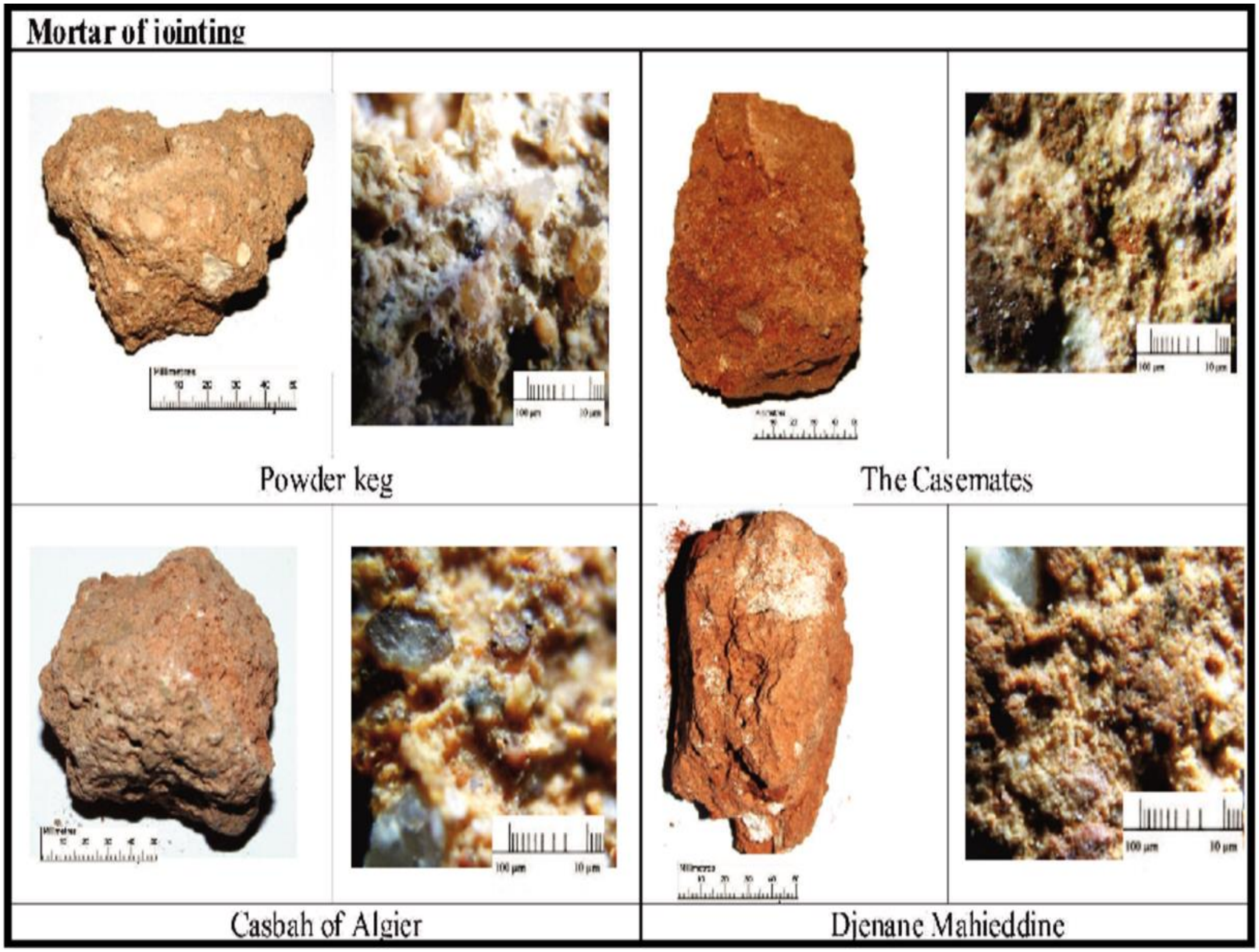

Figure 2. Observation of different samples of jointing mortar: The various samples present differences compared to their texture and their colors.

Coating mortar

All samples of coating mortars studied are presented in Figure 3.

a) The Citadel of Algiers: We have selected two samples:

i) The powder house (MC1): The colour of this mortar is very clear. It is pinky-orange coloured, dotted with some very sparse brown spots and some large quantities of more or less big lime grains. This material is brittle to the touch and to the naked eye, it has a series of pores (Figure 3a).

ii) The Casemates (The pillboxes) (MC2): It is a very light pink coloured mortar, almost whitish, mottled with brown. It is dotted with very small quantities of lime particles. It is compact and has very few pores to the naked eye (Figure 3b).

b) The Casbah of Algiers (MC3): The coating mortar has a very nuanced colour, which ranges from yellow, pink and in some places whitish, which suggests a variety of components. This mortar is dotted with brownish red spots and large quantities of more or less big lime grains. This material is brittle to the touch and to the naked eye, it has a series of pores. Eroded, it has different sized grains and even rubble (Figure 3c).

c) Villa Mahieddine (MC4): It is a reddish pink colour dotted with large quantities of brown spots of various sizes and some more or less big lime grains. It is very brittle to the touch and has a given number of pores that are visible to the naked eye (Figure 3d).

Methods

Here, we chose the complementary analysis techniques, in order to carry out the chemical and mineralogical characterisation of the collected mortar samples. The advantages of this procedure are that the different results directly provide us a great deal of information. By combining the results of physical, mineralogical and chemical analysis, we have been able to identify the elements that compose them and check the first findings, giving us a better insight to the materials.

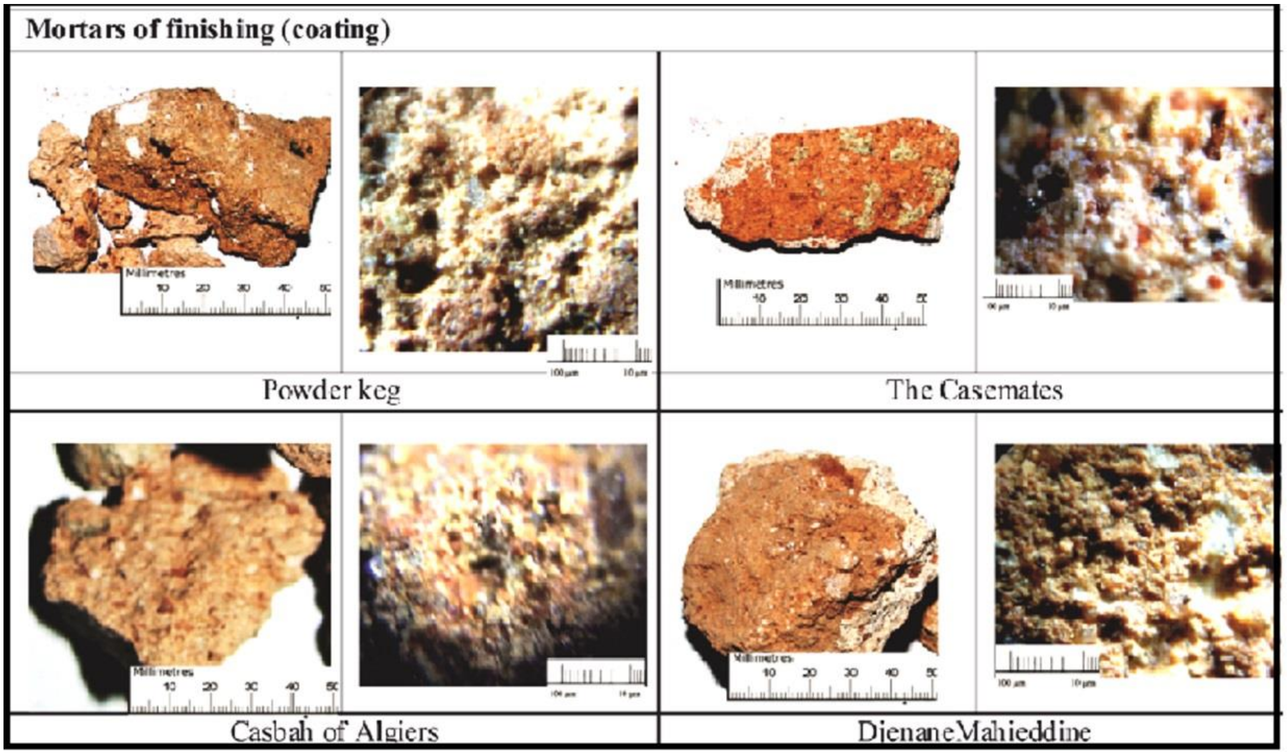

Figure 3. Observation of different samples of coating mortars.

Physical analysis

Physical analysis enables us to identify the specific and apparent densities, as well as the percentage (%) of humidity, porosity and water absorption, according to French standards NF P18-558; NF P94-050; NF P18 554.

Determining the concentration of free lime (CaO) is done via the sucrose method, according to NF EN 459-2. Determining the concentration of free lime (CaO) is based on dissolving the sample in demineralised Water , which is then titrated with hydrochloric acid (HCl), diluted to 5%, and using phenolphthalein as indicator, hence, we can quantify the amount of free lime (CaO) expressed as a percentage.

Mineralogical analysis

Its purpose is to identify minerals and theirs dosage for a quantitative estimate. This study was conducted using X-ray diffraction.

Chemical analysis

The chemical composition of Ottoman mortars was determined by X-ray fluorescence, using the principle of standard NF P 15-467. The loss on ignition is determined at 1000 °C, under the provisions of standard EN 1744-1.

Historical studies pertaining to the Ottoman period refer to the possibility of using natural hydraulic lime in the composition of some mortars, hence the importance of calculating the hydraulic index, in order to verify this hypothesis.

The hydraulic index (HI) is calculated using Equation (1) (Boynton, 1980).

$$HI = \frac{Al2O3\%+Fe2O3\%+SiO2\%}{CaO\%+MgO\%} \quad (1)$$

RESULTS

Physical properties

The results obtained from the physical analysis, are summarised in Table 1. They show that for jointing mortars, the highest value of apparent density is 1. 67 g/cm3 and the corresponding value of the specific density is 2.13 g/cm3. The value of the gap between the two densities is 0.46 g/cm3.

The highest value of apparent density, for coating mortars is 1.87 g/cm3 and the higher value of their specific density is 2.54 g/cm3. The gap between the two values of densities is 0.67 g/cm3.

The sample of jointing mortar MJ4, has a lower percentage of water absorption (12.75%) and porosity (21.59%), than the MJ1 sample, which has a higher percentage of water absorption (20.18%) and porosity (31.89%). Likewise, of the coating mortars, sample MC4, has the lowest percentage of water absorption (13.53%) and a porosity (24.36%), while sample MC2 has the highest percentage of water absorption (18.84%) and porosity (28.84%).

The existence of free lime can be found on all samples, with rates varying from 2.21% to 3.36% for mortars. The

Table 1. Physical properties of mortars.

Samples	Apparent density $P_{apparent}$ (g/cm^3)	Specific density $\rho_{specific}$ (g/cm^3)	Porosity Pt (%)	Absorption of water Ab (%)	Humidity H (%)	Free lime CaO (%)	pH (%)
MJ1	1.58	2.32	31.89	20.18	1.20	2.24	9.42
MJ2	1.63	2.10	32.08	19.68	9.70	2.15	9.91
MJ3	1.42	1.96	27.55	19.40	1.08	2.21	9.83
MJ4	1.67	2.13	21.59	12.75	7.05	3.36	9.85
MC1	1.87	2.54	26.37	14.10	1.99	4.48	9.95
MC2	1.53	2.15	28.84	18.84	2.01	5.60	9.20
MC3	1.47	1.98	27.75	17.51	6.21	1.68	9.32
MC4	1.80	2.38	24.36	13.53	3.46	3.20	9.72

Table 2. Results of XRD analysis.

Minerals	MJ1	MJ2	MJ3	MJ4	MC1	MC2	MC3	MC4
Quartz (SiO_2)	33	45.5	42	40.5	41	57	51	46
Albite ($Na_2AlSi_6O_{16}$)	06	06	06,5	04	06	04	06	05
Orthoclase(K_2 $AlSi_6O_{16}$)	-	-	-	-	-	-	-	-
Gypse ($CaSO_4$ $2H_2O$)	-	-	-	-	-	-	-	-
Calcite ($CaCO_3$)	30	24	32	28	44	24	18	25
Dolomite (CaMg $(CO_3)_2$	-	-	-	-	-	-	-	
Muscovite	15	05.5	02.5	05	05	03	06	06.5
Kaolinite (Al_2 Si_2O_5 $(OH)_4$)	06	-	-	-	-	-	-	-
Hématite (FeO_3)	03	03.5	02	04	-	01.5	04	03.5
Feldspaths K K_2O $6SiO_2Al_2O_3$	05	07	07.5	09	03	04	06	04
Périclase MgO	-	-	-	-	-	-	-	-
Clay materials	-	08.5	06.5	07.5	-	-	07	09
Others	02	01	01	02	01	01	02	01

highest value was found in the MJ4 sample, while in coating mortar, it varies from 1.68% to 5.60% and the highest value found was in sample MC2. The pH of all samples ranged between 9.20 and 9.91.

Mineralogical composition

The results of the XRD mineralogical analysis reported in Table 2, revealed the presence of significant amounts of quartz and calcite. For jointing mortars, the amount of quartz varies between 33 to 45.5% for MJ1 and MJ2 and the amount of calcite varies between 24% for MJ2 and 32% for MJ3, while coating mortars have a quartz amount that varies between 41% for MC1 to 57% for MC2, and a calcite amount that varies between 18% for MC3 and 44% for MC1.

Furthermore, in all samples, the existence of Muscovite, Albite and Feldspars has been found, in amounts that vary between 2.5 to 15% for Muscovite, 4 to 6.5% for Albite and 3 to 9% for Feldspar. Other components, such as Hematite also have a presence in all samples but at levels not exceeding 3.5%.

Apart from MJ1, MC1 and MC2 samples, all other samples contain clay materials in contents that range from 6.5% for MJ4 and 9% for MC4. On the contrary, kaolinite (6%) is present only in the MJ1 sample.

Chemical composition

The chemical analysis results are provided in Table 3. These results show that the most important component of the various mortar samples is SiO_2 with rates ranging from 45.42% for MJ1 to 52.98 % for MJ4 for all jointing mortar samples, while they range slightly higher for finishing mortars, with 49.00% for MC1 and 62.12% for MC2.

The CaO content is also important, however, in a lower percentage than the SiO_2 rates. They range between 13.25% to 17.27% for jointing mortars and 13.63 to 24.38% for coating mortar.

We have also noted significant levels of Al_2O_3, the content of which ranges from 7.29 to 10.96% for jointing

Table 3. Chemical compositions of the mortars Wt (%).

Samples	Wt (%)											Hydraulic Index (HI)
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	P_2O_5	TiO_2	LOI	
MJ1	45.42	10.96	4.31	16.23	1.05	0.24	2.11	0.69	0.06	0.62	16.29	3.51
MJ2	49.64	9.63	2.86	16.59	0.90	0.28	1.63	1.60	0.08	0.32	19.48	3.55
MJ3	52.75	7.29	3.39	17.27	0.48	0.09	1.49	0.75	0.07	0.34	16.08	3,57
MJ4	52.98	9.99	3.27	13.25	0.61	0.13	2.76	1.24	0.05	0.41	15.30	4.77
MC1	49.00	4.05	1.42	24.38	0.30	0.13	0.81	0.67	0.05	0.13	19.07	2.21
MC2	62.12	4.89	1.76	15.29	0.35	0.08	0.96	0.84	0.06	0.17	13.49	4.39
MC3	51.71	10.54	4.11	18.47	1.37	0.15	1.81	0.90	0.12	0.49	10.33	3.34
MC4	55.01	9.69	4.66	13.63	0.56	0.07	1.41	0.55	0.05	0 .47	13.91	4.88

mortars and 4.05 to 10.54% for finishing mortars.

The highest values for the hydraulic index were recorded on the MJ4 sample, for jointing mortars and the MC4 sample for coating mortars. Furthermore, we note that the combination of oxides SiO_2, Al_2O_3 and Fe_2O_3 for each of the two samples (MJ4 and MC4), are very significant (high).

DISCUSSION

Of the set of samples, mortars exhibit a percentage of water absorption that ranges between 12.75 and 20.18%, corresponding to a porosity percentage between 21.59 and 31.89% for jointing mortar samples, and the percentage of water absorption ranges between 13.53 and 18.84%, to which corresponds a porosity percentage of between 24.36 and 28.84% for coating mortar. These results show that the percentage of porosity is proportional to the percentage of water absorption.

It is noted that the samples that have the largest concentrations of quartz and have an addition of broken brick, have the lowest absorption and porosity percentages, whereas those with a significant CaO content, have a higher absorption and porosity percentage.

In addition to our descriptions on the various samples, one can see that samples with the lowest percentage of porosity and absorption have a better state of conservation, as is the case of MJ4 (jointing mortar) and MC4 (coating mortar), both taken at Villa Mahieddine.

Insignificant contents of P_2O_5 in all samples indicate the absence of organic material in the composition of the mortars. The pH of all samples is basic, according to the alkaline characteristics of minerals, which are found in mortars, such as calcite.

The chemical analysis shows the existence of a large amount of Silica (SiO_2) in the composition of the various mortar samples taken from the city of Algiers; the origin of SiO_2 is predominantly sand. There are also significant amounts of lime, which means the existence of calcium carbonate in mortars however, the quantities, are significantly lower than those of the Silica. To be noted, are also the significant amounts of aluminium oxide (Al_2O_3), while the remaining components Fe, Na and K only exist in moderate amounts. This means that broken brick can be found in the composition of mortars.

The XRD analysis of mortar shows the different minerals which composed mortars. The minerals with a highest contents are quartz and calcite (calcium carbonate), the samples of coating mortars have large amounts of quartz, which substantially exceed those found in jointing mortar samples.

The majority of samples, have higher quartz content than calcite content, with exception to the MJ1 and MC1 samples taken from the pillboxes (The Casemates), which have equivalent levels of quartz and calcite (33 and 30% for MJ1 and 41 and 44% for MC1).

To be noted, as regards all of the samples, the presence of smaller amounts of Albite and Muscovite, the source of which is likely to stem from additions of components such as baked brick and crushed or milled ceramic. The MJ1 sample, taken at the pillbox, shows that the mortar of that building contains Kaolinite, which is a clay mineral found in the manufacture of ceramics, while other samples, with exception to MC1 and MC2 samples, contain clay minerals, which confirm the presence of clay in the majority of mortars under study.

The hydraulic index (HI) is significant at the level of all mortar samples. The largest hydraulic index value is raised in the MJ4 and MC4 samples, taken from Villa Mahieddine. Both samples contain Muscovite (05 and 06.5%) and clay materials (07.5 and 09%). This finding allows us to argue that the number of additives, such as crushed bricks and ceramics, influences the hydraulic nature of mortars.

It should also be noted that there is a link between the chemical components of samples and their respective hydraulic indexes. Thus, samples containing a significant hydraulic index have significant levels of the following oxides: SiO_2, Al_2O_3 and Fe_2O_3. This allows us to say that the hydraulic nature of mortars also depends on the nature of the various additives (crushed or broken ceramics or bricks ...).

Conclusion

The mineralogical and chemical compositions of different samples of mortars studied, allow us to identify the raw materials that were used in their manufacture. It shows us that the raw materials used in larger quantities were sand and lime in proportions that vary for jointing mortar, from one-part lime to one and a half (1, 5) parts to two (2) parts of sand (1 to 1, 5 - 2), in the case of samples taken from Casemates (pillboxes), the Casbah of Algiers and Villa Mahieddine. Whereas for these same buildings, coating mortars have a lime/ sand proportion that varies from one (1) part lime to two (2) to three (3) parts sand (1 to 2- 3).

Unlike that of the powder house, this has a lime/sand proportion of one-part lime to one-part sand (1 to 1). This proportion is the same for both the jointing mortar and finishing mortar.

The mineralogical analysis and calculation of hydraulic index have confirmed the hydraulic character of the different mortars studied, and have found that it is influenced by additives such as milled ceramics, crushed bricks and clay materials.

The composition of these mortars is done according to specific proportions of the various components: the most important component, as regards quantity, is quartz , followed by lime, which is used as a binder, and finally, although in smaller quantities, some additives, such as crushed bricks and clay materials.

The percentages of porosity and absorption are significant for most of the mortar samples. These two characteristics are influenced by the quantity of components of mortars. The mortars with a large amount of sand have à lower percentage of porosity and absorption, than the mortars with a smaller amount of sand.

All of these results have enabled us to see the similarities of the mortar components, their respective proportions, and their physical properties, despite the diversity of sites and buildings, which leads us to say that there was a common knowledge in the city of Algiers, which has endured for centuries, given that these buildings were built between the sixteenth and eighteenth centuries.

These results also confirm the composition of mortars that are reported in historical documents and archives of the Ottoman period in Algiers, however, we note that the correct amounts of binder and aggregates that have been mentioned in the works of S.Chergui, (one-part lime to two to three parts sand), are not the same in finishing mortar, while the jointing mortars studied, have been made according to other proportions (one-part lime to one-part and a half to two parts sand).

These physical and mineralogical results allow proposing better mortar preparations, used for restoration and repair the historical buildings. These new formulations of mortars are compatible and have lots of similarities with the ancient mortars.

Conflict of Interests

The authors have not declared any conflict of interest.

REFERENCES

Ait Ouakli S (2010). sous la direction du Pr. M.Hamiane et Pr. O. Boumghar, Elaboration d'un mortier de jointement et restitution 3D «cas du site de la villa Mahiédinne», Mémoire de Magistère, Université M'hamedBougarra, DepartementGenie des matériaux, Boumerdes, 2010.

Ashurst J (1983). Mortars, plasters and renders in conservation. Ecclesiastical Architects' and Surveyors' Association.

Belaidi M (2011). sous la direction du Pr. M.Hamiane ,Etude des caractéristiques des mortiers historiques et proposition d'une formulation pour les mortiers de restauration,cas d'étude « Citadelle d'Alger » Magistère, Institut d'archéologie, Université Alger2, 2011.

Binici H, Arocena A, Kapur S, Aksogan O, Kaplan H (2010). Investigation of the physico-chemical and microscopic properties of Ottoman mortars from Erzurum (Turkey), Constr. Build. Mater. 24(10):1995-2002.

Boukhenouf A (2006). sous la direction du Pr. M.Hamiane. Caractérisation des mortiers archéologiques, le cas des sites historiques de Djemila et de la citadelle d'Alger, Mémoire de Magistère, Université M'hamed Bougarra, Departement Genie des matériaux, Boumerdes.

Boynton RS (1980). Chemistry and Technology of Lime and Limestone, Wiley, New York.

Büttner S, Prigent D (2007). Archéologie des liants de maçonnerie : entre traités et réalité, dans medieval Europe, Paris 2007, 4 eme congress international, d'archéologie medievale et moderne, 2007 (publication electronique), http://medieval-europe-paris 2007.univparis1.fr/S.B%C3%BCttner%20et%20al..pdf.

Chergui S (2007). Construire, gérer et conserver les mosquées en Al-Djazā'ir ottomane, thèse de doctorat 3:834.

Coutelas A (2003). Pétroarcheologie du mortier de chaux gallo-romain. Essai de reconstitution et d'interpétation des chaines opératoires : du matériau au métier antique, Archives ouvertes HAL, 2003, https://tel.archives-ouvertes.fr/tel-00528508/file/Coutelas_2003.pdf

Foufa A (2010). Contribution to the discovery of earthquake - resistant techniques adopted in the large cities of the Maghreb (Algeria, Fez and Tunis) during the XVIII century " (2010) PhD Thesis, Algiers, Épau.

Hamiane M, Ait ouakli S, Boumghar L, Zekagh W, Saidi A (2010). Design of jointing mortar compatible with masonry of the villa Mahiddine of the Ottoman Era, in RILEM proceeding PRO78."Historic Mortars and RILEM TC 203-RHM, Final worhshop, HMC2010.

Kurugöl S, Güleç A (2015). Physico-Chemical, Petrographical and Mechanical Properties of Mortars used in an Ancient Roman Basilica in Amasra/Turkey. Gazi Univ. J. Sci. 28(4):609-21.

Lespès RA (1930). Etude Géographie et histoire urbaines. Librairie Felix Alcan, mai 1930, paris.

Mallinowski R (1982). Durable préhistorique ancient mortars and concretes. Nordic Concrete Research in transportation research board. décembre P 22.

Palazzo-Bertholon B (1998). Histoire, archéologie et archéométrie des mortiers et des enduits au Moyen Âge, Thèse de doctorat, Lyon II - Louis Lumière, Lyon.

Rozert M (1930). Mémoires géologique sur les environs d'alger. journal de géologie 1930. Source gallica.bnf.fr/Biblotheque nationale de France.

Rota Rossi PD (1986). Mortars for restoration, basic requirements and quality control. Mater. Struct. 19:445.