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Nano and Waste-structured Lime-gypsum Mortars for Green Restoration of Cultural Heritage Buildings in Cairo

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ABSTRACT

The retrofitting of heritage buildings largely depends on the strength of the mortar between the stones or bricks. Currently, nano and waste materials represent one of the most efficient and suitable methods for civil and structural applications as reinforcement and repair systems. Nano Reinforced Mortars (NRMs) have received extensive attention for externally bonded reinforcement of historical and masonry structures. Historic Cairo is considered one of the most prominent world heritage metropolises and the largest cluster of heritage architecture worldwide. This work first investigates and elucidates the different properties of the historical lime-gypsum mortars used in monumental buildings. To help identify the characteristics of the historical mortar, different examination methods such as XRD, SEM, EDX and a Compressive Strength Test were used. Next, it investigates the behavior of proposed nanostructured lime-gypsum-based mortars and waste-structured lime-gypsum-based mortars for the restoration and consolidation of traditional mortars used in historical building construction. Based on the developed knowledge and an extensive literature review, it proposes and validates a methodology for improving the consolidation effectiveness of nano and waste materials, making these suitable products for building heritage conservation.

The proposed nano and waste lime-gypsum-based mortar specimens is prepared using Natural Hydraulic Lime (NHL), Metakaolin, Sinai Gypsum (SG), Silica fume, Homra (dust of red brick) and sifted siliceous sand. The previously proposed materials were used in different proposed mix sets in order to make a comparative study of the influence of metakaolin, homra and LBC on the physical and mechanical properties of the mortar mixes. Next, the study verifies the influence of different lime, gypsum and sand replacement ratios on the properties of the proposed mixes. Due to the high durability and mechanical properties of category A4 (Lime: Homra: sand: water with ratio of 1: ½ : 3: 2, respectively) and category D1 (Lime: gypsum: Silica fume: Nano-kaolinite: Homra: sand: water with ratio of 1:½: 1: 1/6: 1/6: 3:2, respectively) can be considered not only a good durability mortar mixture but also a green restoration process by using waste materials.

INTRODUCTION

Historic Cairo is considered the largest cluster of heritage architecture worldwide. It isn't the largest in the number of archaeological buildings of the glorious era but also in the weight of their architectural, artistic, and historic value (Abdulmunim A., 2006). Historic Cairo is the home of a number of historical neighborhoods and significant monuments which characterize the city's architectural wealth, not only as a capital of the Islamic world but as a wonder of the human urban experience.

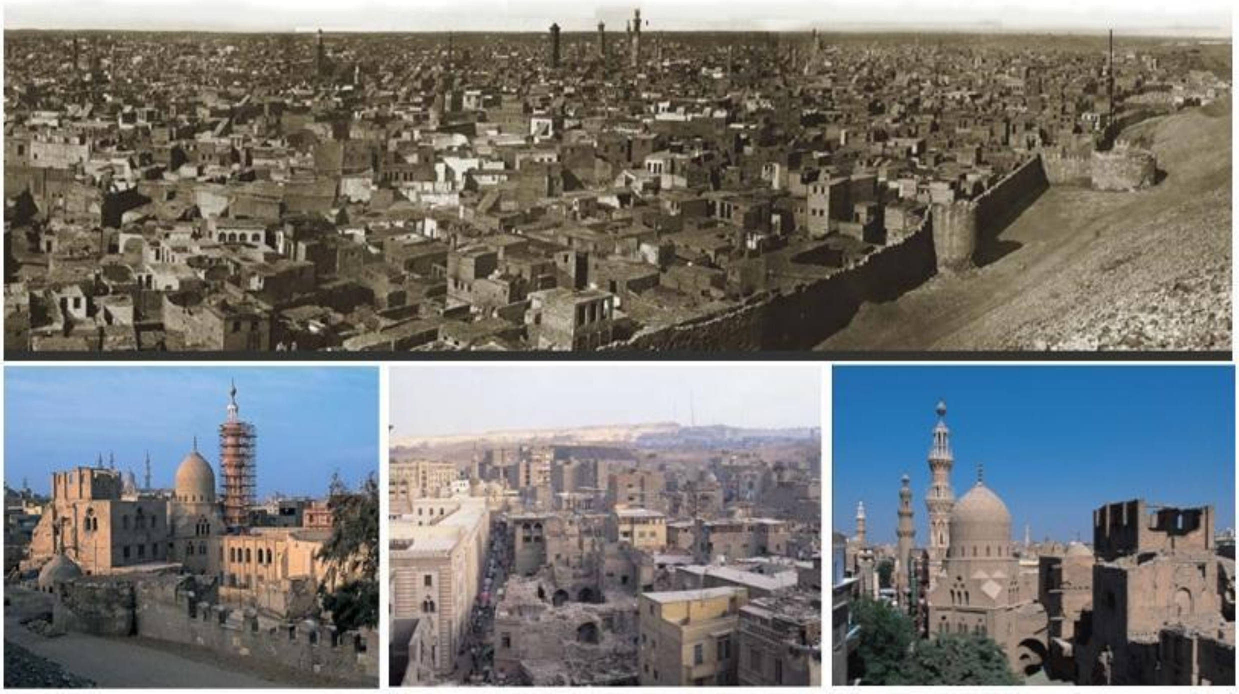

Fig. 1: General views of some historic districts in historic Cairo

In historic masonry buildings, resistance to horizontal actions can mainly accomplished by the stone walls. Otherwise, horizontal forces can generate bowing or warping in the wall structure, which creates tensile stresses in the masonry elements. Tensile strength in masonry elements is only accomplished by the compression state associated with gravity loads and mortar strength. Mortar may have lost part of its bonding properties due to aging, lack of preservation works and the use of poor flexural strength mortar during restoration projects (Lourenço P. 2006, Cardoso R, et al. 2005. Abdelmegeed M, 2015). Since the Greek-Roman era, lime-gypsum-based mortar has been used in Egypt for monument construction (Briggs M., 1974; Christine B., 1997; Abdel-Aty A., 1999; Kshank D., 1996; De-Vekey C., 2001; El Banna A., 2002; Abdelmegeed M. 2009). From a structural point of view, mortar plays a significant function in the construction behavior of historical structures (De-Vekey, C. 2001, Toniolo L., et al. 2010, Lourenço P. 2006, Hansen E., et al. 2003, Borsoi G., et al. 2012). Despite these, the majority of heritage buildings in Cairo have suffered a lot of damage due to various causes (see Fig 2).

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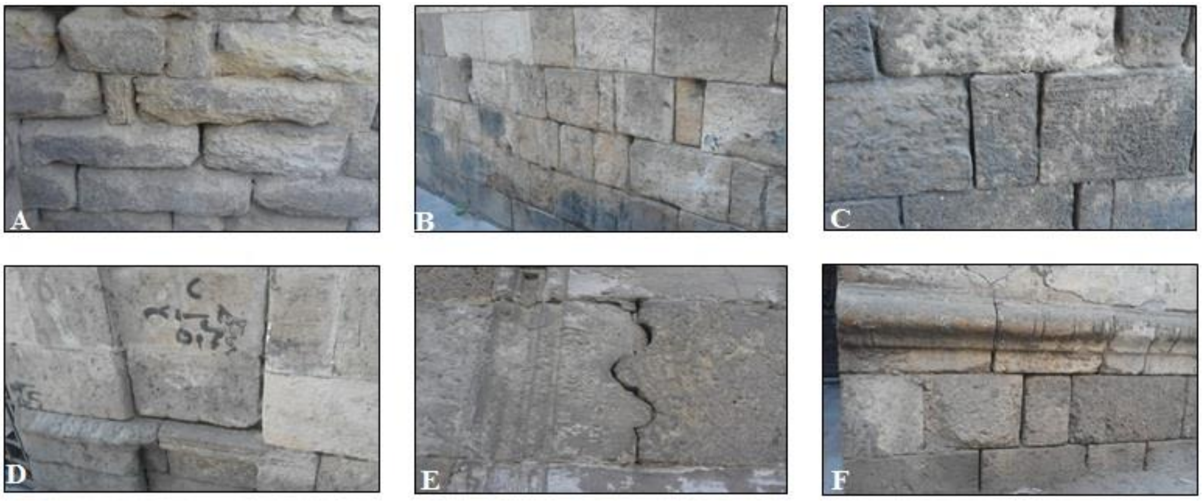

Fig. 2: Mortar deterioration phenomena (bleeding) in historical buildings where; A) Barquq Mosque, B and C) Kaaib El-Ahbaar Mosque, D) Daood Basha Mosque, E) El-Ghoria complex and F) A house in Sayeda Zeinab district

There is a general consensus, at least amongst heritage observers, that traditional mortars typically deteriorate and decay in a slow and uniform form primarily in response to dissolution actions. However, Calcareous, lime and gypsum-based materials are subjected to weathering phenomena (salt fluorescence, bleeding, salt crystallization. etc.). Degradation and dissolution in mortar can lead to surface decay (Khalaf, M., Abdelmegeed, M. 2018, Borsoi, G. et al. 2017, El-Gohary, M. 2010, Borsoi, G. et.al 2016]. Bleeding, sanding, powdering, and chalking are calcareous materials' most common decay phenomena. The previously mentioned decay patterns imply the loss of cohesion, binding materials and thus of mechanical strength [De-Vekey, R. et al. 1990, El-Banna A. 2002, Toniolo, L. et al. 2010, Borsoi, G. et al. 2017, Abdelmegeed, M. 2018). However, mortar in Islamic heritage buildings in Cairo is daily exposed to deterioration due to many factors such as weathering effects, sewage water, air pollution…etc. Other factors are due to man-made actions such as misuse and poor restoration using unsuitable mortars, which, over time, are bleeding or dissolving (Abdelmegeed M. 2009, El-Banna A. 2002, Khalaf, M., Abdelmegeed M. 2018). An in-situ survey of unrestored and restored Islamic heritage buildings in Cairo showed that about 70% to 80% of these buildings suffered from mortar desolation, render bulking, plaster detachment, fragmented mortar and bleeding of the rubble mortar for the infillings of double-bearing walls (Fig. 1). Consolidation treatment can enhance the mechanical properties of deteriorated mortars in heritage buildings. This intervention method, in particular, is used to recover the binding of the grain structure and so enhance the adhesive forces across and between the mineral surfaces by adding and introducing a new binding agent and making organic or inorganic chains or bridges (Toniolo L. et al. 2010, Borsoi G. et al. 2012, Borsoi G. et al. 2017). Nanomaterials made of nanoparticles embedded in mortar matrices are used to strengthen and enhance the bond between mortar grain structures.

In this paper, we have verified three main issues; the first is to improve the effectiveness of nano and waste-structured proposed mortar by enhancing its mechanical properties. The second issue is to verify its compatibility with the aesthetic properties of building materials. The third issue is to verify the durability of the nano and waste structured proposed mortar by improving its resistance to damage actions and mechanisms. The *El-Ashmaoi* Mosque, located in downtown Cairo, is the chosen case study building. The mortar used in building construction suffered a great deal of damage due to various deterioration factors.

EL-ASHMAOI MOSQUE

In the *Elmosqee* district, where the *El-Ashmaoi* Mosque is located, there are many historical buildings. On the west side stands the famous *Abdeen* palace, while on the east side, the famous popular market (*Ataaba*) is located. On the North side stands *Katkhoda* Mosque, where Abdelaazez Street is located on the southern side of the mosque. The El-Ashmaoi Mosque (Fig. 2) was built in 1267H / 1850 AC. The mosque, a one-storey building with a geometrically shaped, rectangular plan, was constructed with local materials. Limestone, lime-gypsum mortar, marble and semi-fired bricks (*Agor* in Arabic) are the building materials used in El-Ashmaoi Mosque construction. The Mosque consists of three main buildings: the first one is the prayer house, the second is the charitable dispensation of water (*Sabil* in Arabic), and the third is the Shrine for Sheikh El-Ashmaoi. The main facade of the building, on *Elashmaoi* Street suffered a lot of deterioration, as is the case with all of the building's construction and architectural elements.

The current information from the in-situ inspection of the mosque, has shown the actual relationship between the building materials deterioration and the surrounding deterioration actions. The mutual relations between building materials properties and deterioration factors represent the deterioration mechanisms, especially with synergetic interactions between different deterioration factors (groundwater, human activities, air pollution, etc.) (Nardi R., 1986; El-Gohary M., 2009, Abdelmegeed M., 2015). The mortar used in the El-Ashmaoi Mosque construction was subjected to significant deterioration phenomena due to the effect of various damage factors (e.g., groundwater, harmful human activities whether un-intended or intended, air pollution, incorrect restoration, etc.). Degradation, powdering, bleeding and dissolution are the most common damage patterns observed in the mortar used in the mosque (Fig 3).

Fig. 3: Mortar damage patterns in the El-Ashmaoi Mosque

We examined the following methodology to verify the decay mechanism in the deteriorated mortar in the building and conclude the deterioration factors affecting the mortar and then recover these defects using a consolidated mortar.

THE CHARACTERIZATION OF HISTORIC MORTAR

The following scientific methods and analytical techniques have been executed to investigate both intrinsic and extrinsic actions that have affected the mortar in order to determine decay mechanisms and forms that occur in the mortar.

SAMPLING

Three samples were taken from different locations of the prayer house and the charitable dispensation. Table 1 defines all details about the taken samples (e.g. locations, height, decay percentage…etc.).

Table 1 detailed clarification of the collected mortar specimens (El-Ashmaoi Mosque)

specimen	**Sample details and visual observations**				
	specimen types	Specimens location	Specimens height*	Specimens' description (Visual and touch)	Decaying range %
L_1	Mortar	Northern wall	2.30 m	Brownish - disintegrated surface	60: 70 %
L_2	Mortar	Western wall	0.45 m	Salty crust- decayed sample	80: 85 %
L_3	Mortar	Northern wall	0.95 m	Salty crust- highly decayed sample	Over 85%

*The measured height of the samples taken according to the Mosque level

The three collected specimens (L_1, L_2, L_3) were investigated, on the one hand, to identify the typology of the mortar used, chemical composition and different decaying patterns and products (e.g., salt profiles and types) (El Banna A. 2002, Böhm B. 2005, Abdelmegeed M., et al. 2015, Khalaf, M., Abdelmegeed M. 2018). On the other hand, the specimens are examined to evaluate and investigate the mortar surface and its components. The analytical instruments used to identify the historical mortar are XRD, SEM and EDX.

XRD TEST

The collected specimens (table 1) have been tested by using the XRD application (model: Panalytical X'pert pro PW 3040/60) to verify the mineralogical composition of the historically used mortar, and the obtained results are shown in Figs (4, 5 and 6), also listed in table 2.

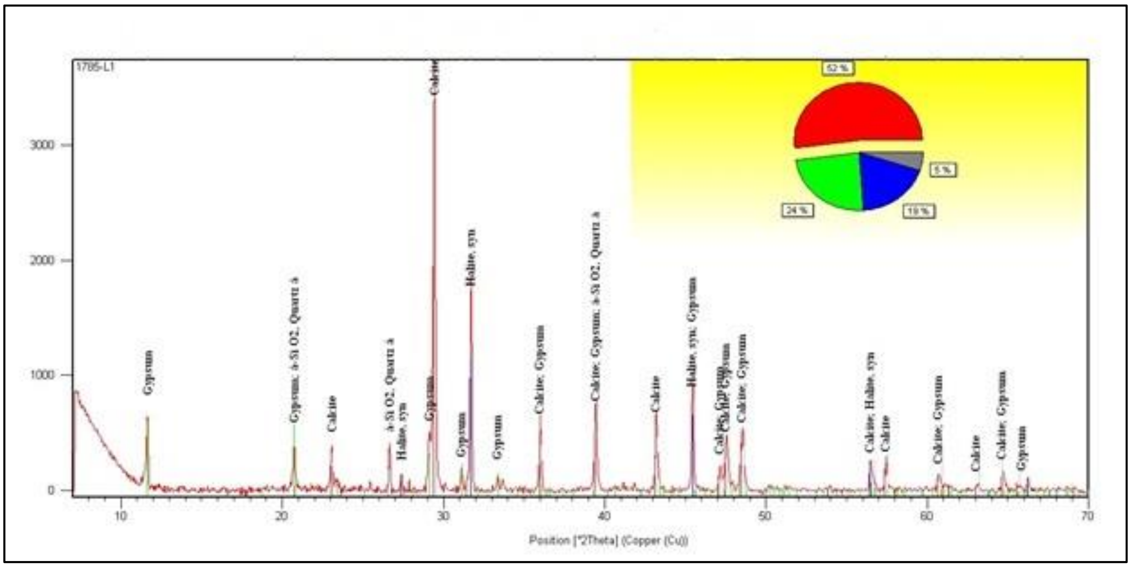

Fig. 4: XRD Patterns of L_1 samples.

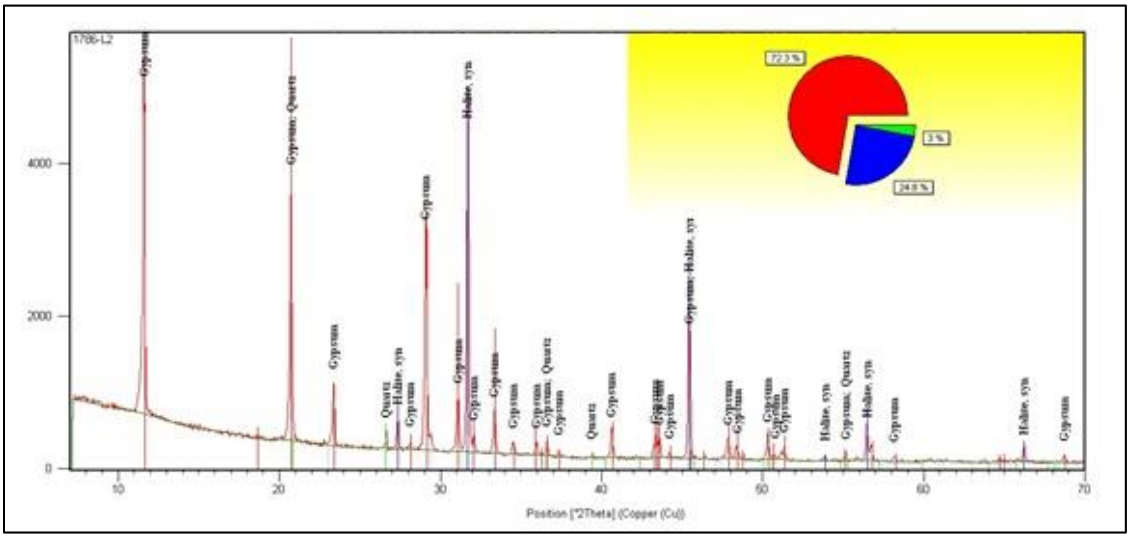

Fig. 5: XRD Patterns of L2 samples

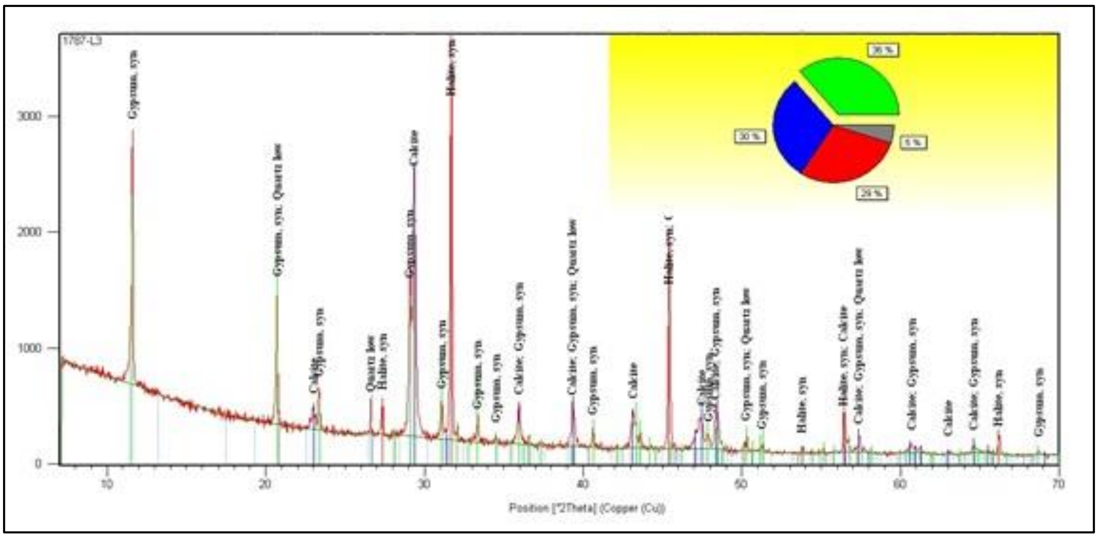

Fig. 6: XRD Patterns of L_3 samples

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Table 2 XRD analytical results of the collected mortar specimens (El-Ashmaoi Mosque)

specimen	Results (minerals)		
	Major	Minor	Traces
L_1	Calcite ($CaCo_3$) – Gypsum ($CaSo_{4.2}H_2o$)	Halite (NaCl)	Quartz (SiO_2)
L_2	Gypsum ($CaSo_{4.2}H_2o$) - Halite (NaCl)	----------	Quartz (SiO2)
L_3	Gypsum ($CaSo_{4.2}H_2o$) - Calcite ($CaCo_3$) – Halite (NaCl)	----------	Quartz (SiO2)

SEM TEST

An Environmental Scanning Electron Microscope (Philips Xl 30 with the analytical conditions 30 Kv) was applied for mineralogical characterization. Three specimens, a, b and c, were examined by ESEM to clarify differences in the morphology of the historic mortar samples (Fig. 6). ESEM images and EDX microanalysis enabled us to prove the results obtained by the direct observation and XRD.

SEM images in Fig. 7 show that the mortar suffered a wide range of decay features. However, a uniform distribution of micro to macro fissures, voids and bubbles was observed. Also, the images show, on one hand, total disintegration and absence of adhered grains. On the other hand, it is noted that the binding matrix is composed of poorly jointed and detached tiny bundles.

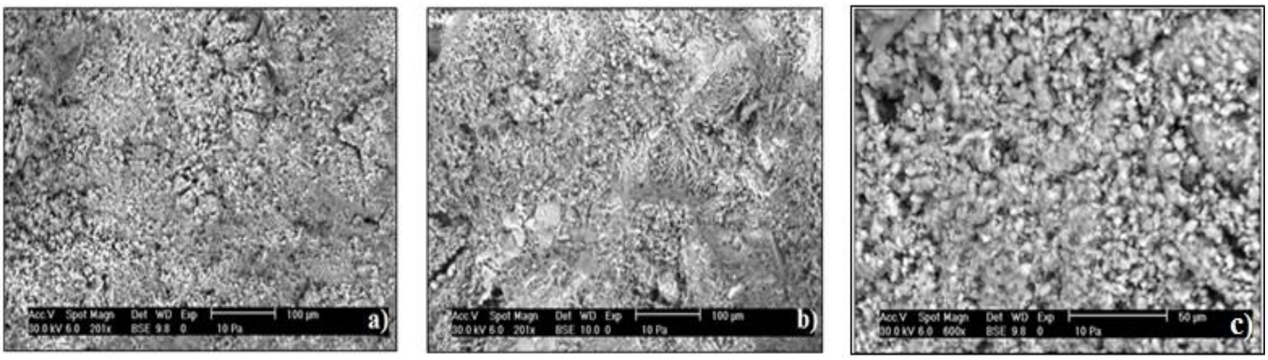

Fig. 7. SEM micrograph, where: (a) shows specimen L_1 (b) shows specimen L_2 and(c) shows specimen L_3

3.4. COMPRESSIVE STRENGTH

The most common, problematic issue in determining the properties of historic mortar, particularly the mechanical ones, is that the extracted specimens are usually small with an irregular shape, making them inappropriate for standardized mechanical tests. The mortar used in historic buildings is mostly lime-based mortar, which is notably used in Carine Islamic monuments. If the lime used is in the form of non-hydraulic, the compressive strength of the mortar can typically be between 0.5-3.0N/mm^2 (Válek, J., Veiga, R. 2005, Zucchini, A, Lourenzo, B. 2006, Maurenbrecher, P., Caspar Groot, 2016, Łatka, D., and Matysek, P. 2018). If the lime used is hydraulic or hydraulic lime with pozzolanic materials or other additives, the compressive strength of the mortar will depend on the amount of the lime and its reactivity in relation to the curing conditions. The expected compressive strength of such mortars is above 1.5 N/mm^2. (Válek, J., Veiga, R. 2005, Maurenbrecher, P., Caspar Groot 2016)

4. THE PROPOSED CONSOLIDATED MORTAR

The proposed new repair mortars need, on the one hand, a specific understanding of the physical, mechanical and chemical properties of historic mortar and, on the other hand, to determine the decay products (Section 3). However, the proposed consolidated mortar is prepared using lime-gypsum mortar with nanomaterials and other additives described in the following section.

4.1. MATERIALS AND METHODS

4.1.1. Materials

Lime-gypsum-based mortar specimens were prepared using: -

- ***Lime***: a commercial Suez-hydrated lime (slacked $CaOH_2$) powder, a commercial product supplied by Suez company (EN 459-1 CL70-S satisfying BS EN 459-1)
- ***Gypsum***: Sinai Gypsum (SG),
- ***Aggregate*****:** (sifted siliceous sand 5 µm): The aggregate sand (quartz) was sieved to ensure that the used sand satisfied the third grading zone of ES 1109/71. The sand was used in a washed and dried condition in all mortar mixes.
- ***Nano-kaolin***: (Metakaolin Cal K): Nano-kaolin obtained by the calcination of kaolinitic clay at high temperatures in the range of 600-900ºC: Sabir B., et al. 200, Badogiannis, E., et al. 2005, Nadia Bianco et al. 2013, Wong, L., et al.2012), from commercialized, nano-kaolin a nationally produced Metakaolin with light coffee coloring.
- ***Homra***: (Fired brick dust): homra is the Arabic name for the dust or the powder produced by crushing red bricks. Red bricks are created from burnt shale or *Tafla* in Arabic. Tafla is a sedimentary rock containing montmorillonite, kaolinite and illite minerals (Russlan A., et al., 2018; Nadia Bianco et al., 2013, Wong L., et al., 2012).
- ***Silica fume:*** Silica fume, or (micro silica), is a waste material by-product from the kiln waste smoke of the production of silicon and ferrosilicon metals. The diameter of the rounded particles of silica fume ranges from 0.15 µm to 1 µm. Thus, these particles are 100 times smaller than cement particles. Accordingly, Silica fume is considered a good filler to fill the cavities between larger particles in mortar compounds. Thus, using such ultrafine material fulfils a dense matrix that enhances the physical, mechanical and durability properties of the mortar (Daman K. Panesar 2019, Bajaber, M.A & Hakeem I.Y. 2021).

4.1.2. Preparation of the proposed mortar mixes

Samples were prepared in two forms. The first form is the standard specimens, as shown in Table 3. In this form, the mortar binders to the aggregate ratio (in volume) were in two categories (Table 3). The second form is the proposed mortar mixes (Table 4). The second form was prepared using a mineral additive (replaced) by the ratios given in Table (1) to the standard specimen mixture. The ratio of water to binder 2:1 (in volume) was adopted for the preparing mortar to have optimal workability.

Table 3: The composition of the mortar standard specimens

Specimen ID	Binders			aggregate (Sand)	Water
	Lime	Gypsum	White cement		
A	1	1/4	-----	3	2
B	2	1/2	-----	3	4
C	1	1/2	1	3	2
D	2	2	2	3	4

The ratio of the materials by volume

The proposed strengthening mortars are prepared in four categories (1, 2, 3 and 4), as shown in Table 4.

Table 4: The composition of the proposed specimen's mortar

Sample ID	Binders		Mineral Additives				aggregate (Sand)	Water
	Lime	**Gypsum**	**Silica fume**	**Nano (Meta) kaolin**	**Homra**	**White cement**		
$\mathbf{A_1}$	1	1/2	-----	1/6	-----	-----	3	2
$\mathbf{B_1}$	**2**	**1**	-----	**1/6**	------	------	**3**	**4**
$\mathbf{C_1}$	1	1/2	1	1/6	------	-----	3	2
$\mathbf{D_1}$	**1**	**1/2**	**1**	**1/6**	**1/6**	------	**3**	**2**
$\mathbf{A_2}$	1	1/4	------	1/6	------	------	3	2
$\mathbf{B_2}$	2	1/2	------	1/6	------	------	3	4
$\mathbf{C_2}$	1	1/2	------	1/6	1/3	------	3	2
$\mathbf{D_2}$	2	1/2	------	1/6	1/3	------	3	4
$\mathbf{A_3}$	1	1	1/6	------	------	------	3	2
$\mathbf{B_3}$	2	1	1/6	------	------	------	3	4
$\mathbf{C_3}$	1	1/2	1/6	------	1/3	------	3	2
$\mathbf{D_3}$	2	1/2	1/6	------	1/3	------	3	4
$\mathbf{A_4}$	1	----	------	------	1/2	------	3	2

The ratio of the materials by volume

4.1.3. Methods

Cubic specimens of lime- gypsum-based mortar (5cm x 5cm x 5cm approximately) and cubic specimens of lime- gypsum-white cement-based mortar (5cm x 5cm x 5cm approximately) were prepared (as described in 4.1.1 sections) and stored in open-air conditions for more than 3 months (≤ 90 days). Afterwards, cubic specimens of lime-gypsum-Nano-kaolin based mortar

(5cm x 5cm x 5cm approximately) and lime-gypsum-white cement-Nano-kaolin based mortar (5cm x 5cm x 5cm approximately) were prepared (as described in sections 4.1.1). Finally, cubic mortar specimens of and lime- gypsum-white cement-Nano-kaolin- *Homra* were prepared. The specimen's typology and the type of additive materials used in the different tested samples are described in Table 3.

4.2. ASSESSMENT OF THE EFFECTIVENESS OF THE PROPOSED MORTAR

4.2.1 SEM test

The proposed mortars in categories containing nano-kaolin, silica fume and brick dust (*Homra*) create reactivity interaction with Ca(OH) (Lime), leading to a decrease in the pore-size systems A, B, C and D, leading to the formation of compact layers composed as showing in Figs. 8, 9 and 10.

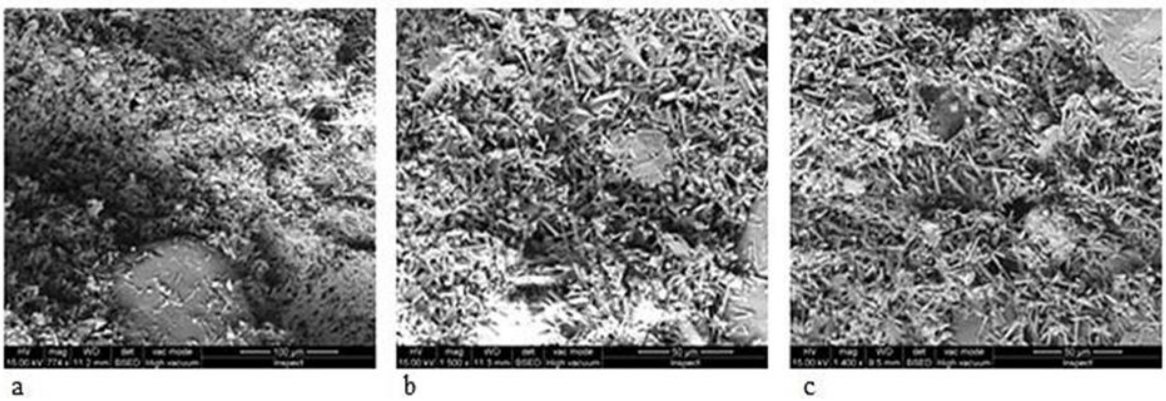

Fig. 8 SEM electro-micrograph of mortar where a and b for category **A** and c for category **B**

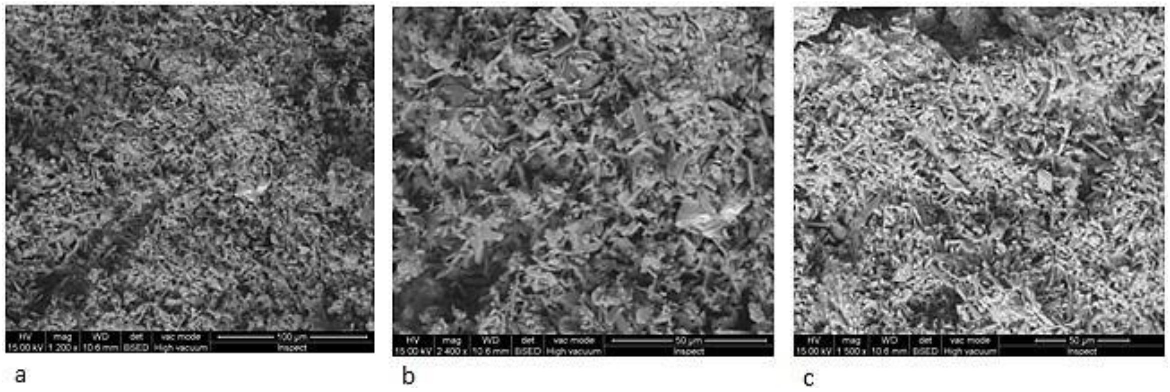

Fig. 9 SEM electro-micrograph of mortar where: a and b for category **C** and c for category **D**

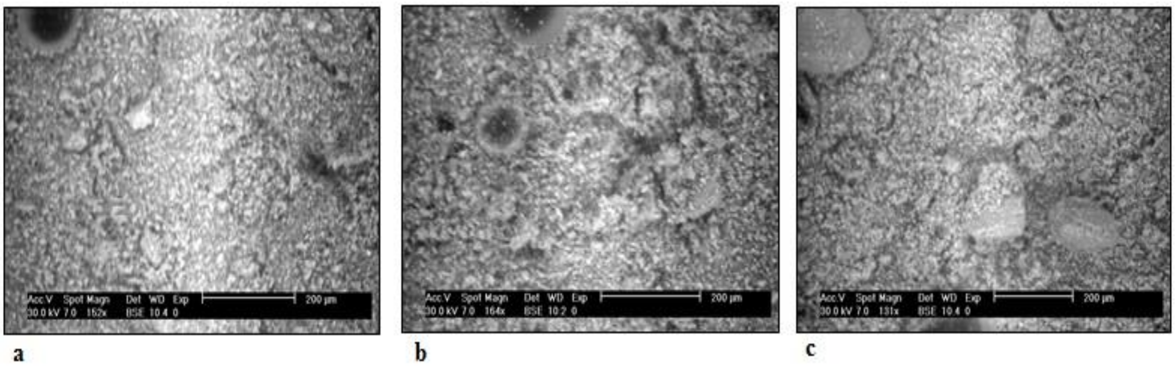

Fig. 10 SEM electro-micrograph of mortar where: a for category B_3, b for category D_3 and c for category D_2

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4.2.2 Compressive strength

Compressive strength is a quality control indication of the mortar's hardness and durability (Maurenbrecher P., Caspar Groot 2016, Válek J., Veiga R. 2005). The compression test was applied with EN 196-1:2005, and the maximum applied load was automatically recorded and converted into stress. Initially, the compressive strength of all mortar samples was explored according to EN 196-1:2005& ASTM C109 using 6 cubes [5×5×5 cm] cubic samples. The obtained compressive strength is shown in Table (5)

Table 5: The compression test values of prepared mortars after 90 days to 300 days

Sample ID	**Dimensions (cm)**			**Age (month)**	**Weight (Kg)**	**Failure Load (KN)**	**Compressive strength (Kg/cm^2)**
	Sid a	**side b**	**height**				
A_1	5.02	5.00	5.00	10	0.214	1.50	5.95
B_1	4.95	5.00	4.94	10	0.205	1.85	6.20
C_1	5.00	5.00	4.95	10	0.210	2.20	8.95
D_1	4.90	4.95	4.95	10	0208	3.25	15.60
A2	4.90	5.00	5.00	10	0.210	1.50	6.122
B2	5.00	5.1	5.00	10	0.211	1.80	7.058
C2	5.00	5.00	5.00	10	0.206	1.20	4.800
D2	4.9	5.00	5.20	10	0.206	2.00	8.163
A3	5.00	5.00	5.00	10	0.195	0.40	1.600
B3	4.8	5.10	5.20	10	0.194	1.80	11.500
C3	5.00	4.80	5.00	10	0.200	1.60	6.666
D3	5.00	5.00	5.00	10	0.201	3.50	14.000
A4	4.80	4.80	5.00	10	0.219	4.50	19.531

5. RESULTS AND DISCUSSION

Mortar in historic masonry buildings may have lost some of its structural function bonding properties due to many deterioration factors such as aging, lack of preservation, weathering acts…etc. Using alternative mortar with some new additive materials will enhance the mortar's physical, mechanical and durability properties. Hence, the idea of creating different mortar mixtures whose main component is the traditional bonding materials used in the ancient mortar, which is lime and gypsum, with the addition of some additional components of nanomaterials or waste materials will give the mortar some distinctive physical and mechanical properties.

for the different mortar categories mixtures (A1-4, B1-3, C1-3, and D1-3) see table 4 and 5 also Fig 9.

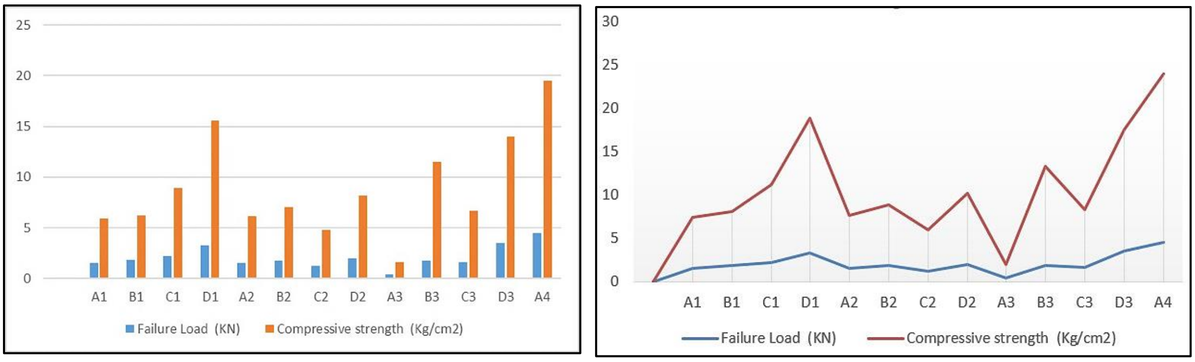

Fig. 11 Compressive strength values of different mixtures

From Fig.11, it can be concluded that the mortar category A4, which consists of Lime: *Homra*: sand: water with a ratio of 1: ½ : 3: 2, respectively, when compared with the other mixture categories, has the maximum value for pressure resistance (compressive Strength). The development of compressive strength for this mixture depends on the rate of reactivity of the pozzolanic material in *Homra* with free lime in the mixture during the early period of hydration because of its high surface energy of interaction. However, this mixture wants more than 3 days for the initial curing (drying) process.

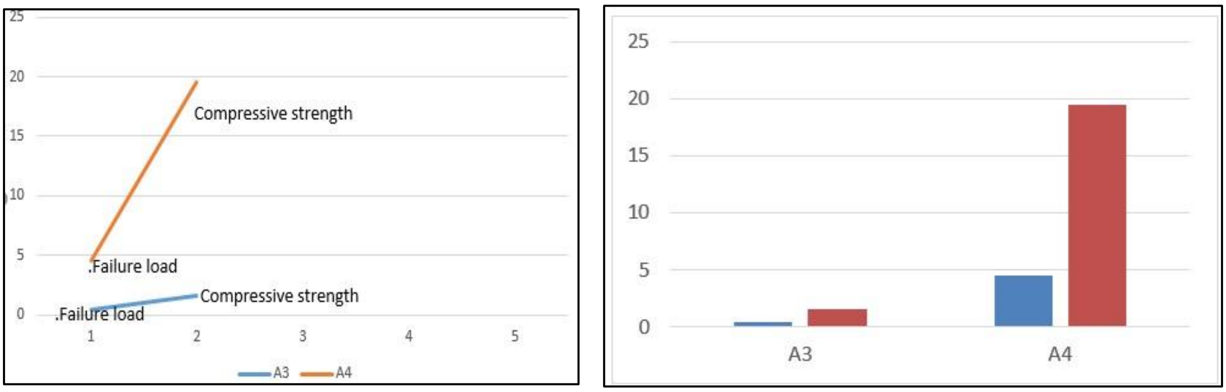

Fig. 12 Compressive strength values of mixture A4 (high value) and A3 (low value)

Also, by comparing the results of pressure resistance between different mixtures, it is noted that there is a significant difference in values between some mixtures, such as in mixtures A3 and A4, where the range was 18 times (see Fig.12).

Otherwise, the value difference was close in other mixtures, such as mixtures B1: A2, C1: D2 and D1: B3, where the values ratio ranged between 0.5: .75 times. The following figure (Fig.13) shows the values of compressive strength comparison. Otherwise, it was observed that mortar mixtures in which the mixture components contain a relatively high percentage of gypsum compared to lime, it was found that the closer the ratio of gypsum to lime, the lower the compressive strength ratio. This observation appeared clearly in mortar mixture A3, in which the ratio of lime to gypsum was 1:1. However, it also observed that in sample No. B3, the percentage of compressive strength increased despite the high percentage of gypsum compared to the percentage of lime. This may be attributed to the presence of silica fume, which is considered a good filler to fill the cavities between larger particles in mortar compounds (lime, gypsum and sand), leading to raising the value of compressive strength, as shown in Fig. 14.

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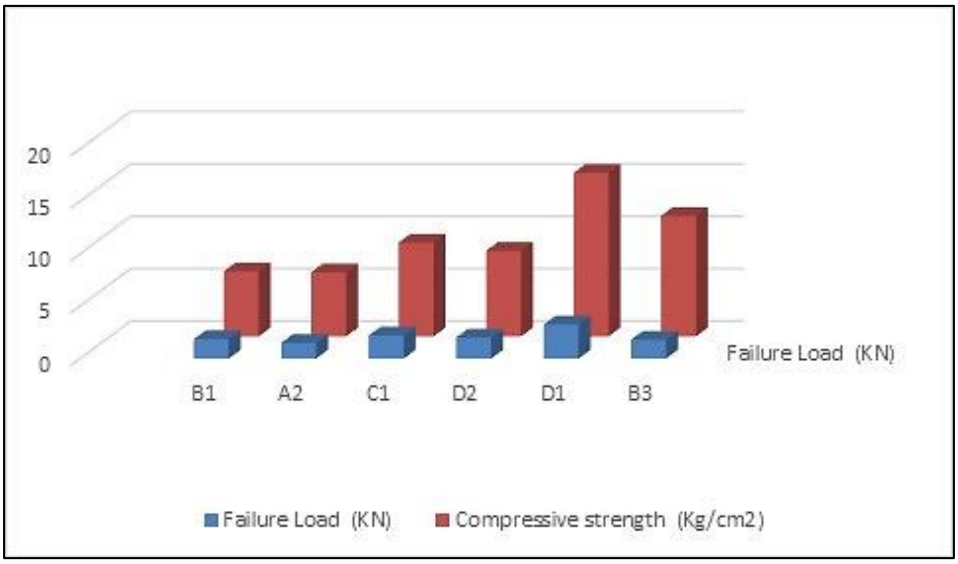

Fig. 13 compressive strength values ratio of mixture B1, A2, C1, D2, D1, B3

On the other hand, Figs. 8, 9 and 10 show the microstructure of the tested mixture mortars under scanning electron microscope (SEM), which shows the variation of the microstructure of these 13 mixtures depends on the variation of the physio-mechanical properties. Hence, we can find that the mortar mixtures that contain products or mineral additives of Homra, silica fume, and nano-kaolin have the best building microstructural elements compared with the ancient mortar microstructure. Thus, we can conclude that after the addition of the burning mineral additives, it forms vitrified products containing more reactive silica and alumina. Hence, using such ultrafine material fulfils a dense matrix that enhances the mortar's physical, mechanical, and durability properties.

Sample ID	Lime	Gypsum	Failure Load (KN)	Compressive strength (Kg/cm^2)
A_1	1	0.5	1.50	5.95
B_1	**2**	**1**	1.85	6.20
C_1	1	0.5	2.20	8.95
D_1	**1**	**0.5**	3.25	15.60
A_2	1	0.25	1.50	6.122
B_2	2	0.5	1.80	7.058
C_2	1	0.5	1.20	4.800
D_2	2	0.5	2.00	8.163
A_3	1	1	0.40	1.600
B_3	2	1	1.80	11.500
C_3	1	0.5	1.60	6.666
D_3	2	0.5	3.50	14.000
A_4	1	----	4.50	19.531

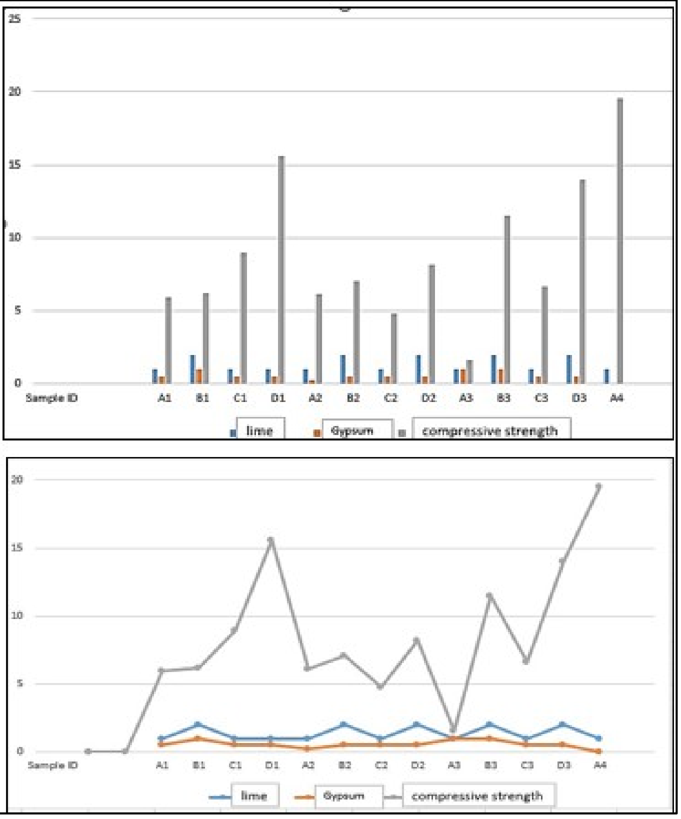

Fig. 14 shows the ratio of gypsum to lime in the sample and the compressive strength ratio.

6- CONCLUSIONS

The bearing walls in Historic buildings form the main part of their structural system. These walls are built with inert semi-chiseled, random and/or regular stones (limestone, sandstone, and marble) and bound together with mortar in two interlocking layers. Traditional mortars, which consist of binders like lime and gypsum nowadays, suffer a lot of deterioration problems due to their poor physical and mechanical properties. Bleeding and fragmentation of mortar are deemed to be the most common damage appearing in historic buildings. The use of alternative mortar with some new additive materials in the restoration of historic mortar will enhance the physical, mechanical and durability properties of the mortar used. Hence, the idea of creating different mortar mixtures whose main component is the traditional bonding materials used in the ancient mortar, which is lime and gypsum, with the addition of some additional components of nanomaterials or waste materials will give the mortar some distinctive physical and mechanical properties.

Based on the results obtained for different mortars with and without pozzolanic additives (Homra, Nano-kaolin and Silica fume) with sifted siliceous showed that the use of pozzolanic materials additives to mortar components gives it good mechanical properties and durability. From the point of view of the green restoration of historical buildings, the use of lime/gypsum-based mortar with waste, natural additives, and/or nanomaterials achieves different physical, mechanical, and durability properties.

Due to the high durability and mechanical properties of category A4 (Lime: Homra : sand : water with ratio of 1: ½ : 3 : 2 , respectively) and category D1 (Lime: gypsum: Silica fume : Nano-kaolinite : Homra : sand : water with ratio of 1: ½ : 1 : 1/6 : 1/6 : 3 :2, respectively) can be considered not only a good durability mortar mixture but also green restoration process by using waste materials.

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مونة الجير والجبس الهجينة من النانو ومخلفات المواد لأعمال الترميم الأخضر للموروث والمباني التراثية في القاهرة

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الملخص

تعتمد عمليات تقوية وترميم المباني الاثرية والتراثية بصوره كبيرة على تقوية المونة الموجودة بين العراميس الافقية والرأسية الرابطة لأحجار أو بلوكات البناء المستخدمة في تشيد تلك المباني. وفى الفترة الحالية تعتبر استخدام تطبيقات النانو ومخلفات المواد من التطبيقات الأكثر فعالية وتأثيرا في تقوية المباني الاثرية والتراثية التي تعتمد عليها نظريات تقوية المباني في العلوم المختلفة. وقد أظهرت أستخدام المونة المقواه أو المسلحة بالمواد النانوية (NRMs) فاعلية جيده في تقوية المونة المستخدمة في المباني الاثرية والتي ينعكس تأثيرها الايجابى في تقوية المباني نفسها .وتعتبر القاهرة التاريخية واحدة من اهم المدن التاريخية على مستوى العالم والتي تحتوى على مجموعات من المباني التاريخية والتراثية التي ترجع لعصور تاريخية وحقبات تاريخية مختلفة. وهذه الورقة البحثية تتناول طرق أستخدام مونة مبتكرة تتكون من الجير والجبس والمواد النانوية أو مخلفات المواد. وقد بدأت الورقة البحثية بمناقشة مظاهر التلف وعوامل التلف التي تعانى منها المونات الاثرية في المباني التاريخية والتراثية والاثرية بمختلف تاريخ هذه المباني، بعد ذلك تم التعرض لأعمال الفحوص والتحاليل المختلفة للتعرف على مكونات المونات في المبانى الاثرية والتراثية وكذلك الخصائص الفيزيائية والميكانيكية إضافة الى التعرف على مظاهر التلف ومكوناتة.

أنتقلت الورقة البحثية بعد ذلك لعمل مونات تتكون من نفس المكونات التي تتركب منها المونة الاثرية والتي وجد أنها تتركب من الجير والجبس ومن ثم تم أضافة بعض المحسنات او المواد التي تزيد من تحسين الخصائص الفيزيائية والميكانيكية لتلك المونات عن طريق إضافة مواد نانوية مثل الميتاكولينا/نانوكاولينا أو السليكافيوم أو إضافة مخلفات المواد مثل الحمرة. كما تم عمل خلطات مختلفة تحتوى على نسب مختلفة من المواد سالفة الذكر. وتم اختبار الخصائص الفيزيائية والميكانيكية لعينات من تلك الخلطات ومقارنة النتائج للوقوف على أفضل النتائج من تلك الخلطات. وقد أكدت النتائج أن الخلطة الرابعة A4 والتي تتكون من الجير : الجبس: السيليكافيوم: نانوكاولينا: الحمرة : الرمل : الماء الخالى من الاملاح بنسب ١:½: ١: ٦/١: ٦/١: ٢:٣، تعتبر من أفضل المونات التي لها القدرة على مقاومة عوامل التلف المختلفة وبالتالي يوصى بأستخدامها في أعمال ترميم وتقوية المباني الاثرية والتراثية.

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الكلمات الدالة

تقليدي، المونة، القاهرة التاريخية، التلف، التقوية، ميتاكولينا، الحمرة، تحسين، الترميم الاخضر