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DOCUMENTATION AND EXAMINATION OF THE EXTERNAL FACADE ARTIFICIAL STONES OF THE OLD HEADQUARTERS BUILDING OF AL-AZHAR SHEIKHDOM, CAIRO, EGYPT

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Abstract:
Artificial stones as plasterwork and rendering in Mohamed Ali Family period are an important component that has been widely used in construction procedures, to implement decorative elements or as a mortar for the facades of historical buildings. Therefore, this study aimed to document, diagnose and identify the components of artificial stones in the external facades of the old headquarters building of Al-Azhar Sheikhdom in Cairo, which it dates back to the nineteenth century. Moreover, the study also aimed to evaluate the condition of the artificial stones in order to choose the appropriate materials and methods for treatment and maintenance. AutoCAD program was used to document the sectors and facades of the building. Portable Digital Optical Microscope, Polarizing Microscope, Morphological Examination with Scanning Electron Microscopy (SEM), X-ray Powder Diffraction (XRD), Energy Dispersive X-Ray (EDX) and Portable X-ray Fluorescence (pXRF) were used. Results showed that the binder material is Portland cement, crushed limestone as aggregate material with coarse sand were used. Moreover, the results showed different forms of deterioration and damage aspects as: disintegration, separation and cracks, which require intervention for treatment.

1. Introduction

Stucco works monuments are varied between museum and architectural stuccoes as moulds, funeral stucco masks, pigmented or gilded ground preparation layers of cartonnage and coffins, mihrabs, minarets and stucco windows from ancient Egyptian periods, Greek Roman and Islamic periods [1-10]. Scagliola, Sgraffito, Pargetting, Marrezo marble and artificial stones were used extensively in Mohamed Ali Family period as internal and external cladding in Egypt [11]. Many historic buildings contain artificial stones; which can be defined as a mixture made of hydraulic or Calcareous binder mixed with aggregate, water and other components [12]. However, since the end of the nineteenth century, the term "Artificial stones" in architecture booklets and dictionaries refers to all these materials obtained through mixing (sand, gravel, and water with lime, gypsum or Portland cement), which give the same properties of natural stones [13]. Feilden has stated that artificial stones are made of fine and coarse gravel, Portland cement, sand, a color of some mineral oxides used to give the desired color, and other additions mixed with water [14]. While Ersen et al. has indicated that powder and crushed bricks, charcoal and many organic fibers, which include straw, hair and other materials, was among the common components of artificial stones [12]. Since the Renaissance Era and thereafter, and after the invention of a new binding material known as (Por-tland cement), architects such as Palladio, Bernini and others have used artificial stones to ensure more durability of their works with the characteristics and appearance of natural stones [15]. The use of artificial stones has widely spread, especially at the end of the nineteenth century as a result of discov-ering the Portland cement in the United Kingdom in 1845 AD. Artificial stones have replaced natural stones, especially in the nineteenth century. Artificial stones are not expensive, and they save time also characterized by their smooth surface [12,14-16]. Moreover, the Portland cement provides artificial stones with mechanical characteristics that are homogeneous in the overall thickness [17]. Artificial stones material have been used in many buildings' facades in the late nineteenth century and early in the twentieth century; it was used in construction and craft industries by using hand-crafted moldings applied directly and as a paint for wall surfaces [12]. Natural and artificial stones, of many historic buildings, especially in Cairo, are exposed to various forms of weathering process and suffering from physical, chemical and biological factors of damage cause a change in physiochemical and mechanical characteristics of artificial stones which threaten the survival and durability of these materials [18-20]. Various methods of investigations and analyses were applied for examining the components of artificial stones and evaluating the condition of the external facade of the old headquarters building of Al-Azhar Sheikhdom to be able to select the proper methods and materials in maintenance and remedy processes [21-24].

2. Materials and Methods

Some samples collected from Al-Azhar Sheikh dome were submitted to some examination and investigation studies to identify the chemical composition of their artificial stones and deterioration products. Various documentation processes, tests, and analyses have been conducted at the old headquarters of Al-Azhar institute as set out in fig. (1).

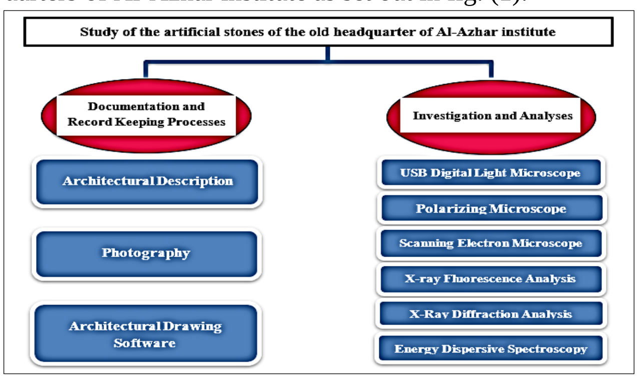


Figure (1) the methodology used in the current study.

2.1. *Documentation*

2.1.1. The historical documentation

The Al-Azhar Institute's original headquarters were established in 1933. King Fouad, I had it built, and was opened in 1933 AD. It is situated at Al-Azhar St., next to the Al-Azhar Mosque.[25] fig. (2). This building is considered one of the most beautiful establishments in the area including the two universities of Al-Azhar at A-Darrasa and Khan El-Khalili Market. It is well known that there were passages down the road linking between the old headquarter of the Institute and the courtyard of Al-Azhar Mosque, through which Al-Azhar Sheikh passes for praying in the mosque on prayer times; however, this passage has been closed long ago.

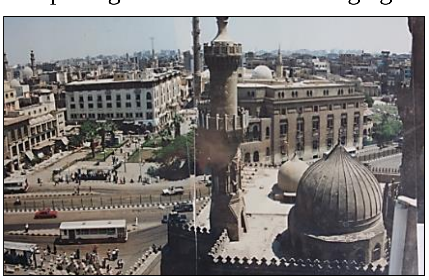


Figure (2) an aerial view of the Al-Azhar Institute old headquarter.

2.1.2. Architectural description of the building

The architectural description means according to the researcher's description obtaining information about the artistic style of the building, its architectural components and their characteristics, function of the building and the modifications made; in order that we can identify the vanished areas, track any changes or encroachments on this monument, describe and record the current condition [26]. It has been confirmed the need and importance of architectural description for historic and ancient structures; as it is necessary to mention the arc-hitectural composition throughout their lifetime [27]. As well as learning about the events for which the building has exposed throughout the years, in order to facilitate understanding the circumstances led to the damage processes it has incurred [28]. Accordingly, researchers have conducted a full description of the building, which includes description of the general site, measurements, façades, decorations and all architectural details.

2.1.3. Photography

Photography is one of the necessary and important processes for recording and documenting historic and ancient buildings, as well as for practical studies applied before restoration and maintenance [29-30] and hence, for a factual photographic documentation for the building, subject matter of study; and for the demonstration of the current condition of the building and manifestation of damages to the artificial stones in the building of Al-Azhar institute. Nikon COOLPIX B500 HD 16 MP camera has been used; in addition, a precise photographing of all building façades, interior voids, decorations and all architectural and artistic elements has been conducted.

2.1.4. Architectural documentation using engineering drawing software

Due to the importance of using engineering drawing software in the architectural documentation of the historic and ancient buildings [26], and decoration works and details of all kinds [28] AutoCAD Software 2020 was used in architectural reporting and documentation works of horizontal and vertical segments and voids. In addition, documentation for all architectural and decorative elements, such as doors and windows, are illustrating the precise decorative elements of the building. Moreover, the manifestations of damage have been set out on the drawings according to a specified scale creating keys for each manifestation.

2.2. *Investigations and analyses*

2.2.1. USB digital light microscope

USB Digital Light Microscope (USB 2.0 interface, Linux, Mac OS & above 10.5.5, from (10X-500X), Model: PZ01) has been used at magnification power of 35 times in scanning the morphology surface of the samples and manifestations of damage. It has been used

2.2.2. Polarizing microscope

A polarizing microscope, (Nikon Eclipse LV100POL (DS-FI1) Made IN Japan); which is present at the Geology dept. of the Housing and Building National Research Centre; has been used to identify the mineral composition of the samples; through studying some of the optical properties of the minerals composing them, such as twinning, extinction and refractive index; in order to identify the texture, size of particles damage in the samples [31].

2.2.3. Scanning electron microscope attached to Energy Dispersive X-Ray Spectroscopy (SEM-EDX)

A morphological examination has been carried out for the artificial stone samples by using a scanning electron microscope provided with an Energy Dispersive X-Ray Spectroscopy (EDX), Quanta 250 FEG (Field Emission Gun); which is present at the National Research Centre in Egypt; with the following technical details: Accelerating voltage 30 K. V; Magnification 14× up to 1,000,000 .and resolution for Gun. In K550X Sputter Coater, England.

2.2.4. X-ray Diffraction (XRD)

The artificial stone samples have been analyzed by using an X-ray diffractometer, (Diffractometer-PW 1480-Netherland. Philips analytical x-ray b.v.); which is present at the National Institute of Standards.

2.2.5. X-ray Fluorescence Analyzer (pXRF)

Portable X-ray fluorescence analyzer, (Thermo Scientific™ Niton™ XLp 300 Series XRF analyzer) was used in the National Research Centre in Egypt.

3. Results

Examination and analysis of the thin sections of the prepared samples, as well as the analysis of the samples collected from the artificial stones that were damaged and deteriorated at the old Al-Azhar institute headquarters, provided significant data. It was found that the binding material is industrial Portland cement, and in regards to the aggregate, it is smaller in size and tends to be lighter in color, such as white sand and crushed limestone. The approximate proportion of the binder (mediator) to the aggregates has been found through a petrographic examination conducted using a polarizing microscope. This ratio is about 1:3. A strong whole-body binding was observed in all samples, as there were no voids or spaces between the particles, which indicates good preparation and mixing for the artificial stone mixture. Furthermore, the images obtained by scanning electron microscopy show that the artificial stones have many manifestations of damage and deterioration, such as cracks in different sizes and damage and erosion in the mineral particles composing the artificial stone samples. The findings have confirmed the need to carry out the necessary remedies, particularly a strengthened process in order to preserve such artificial stones in the building, subject matter of study. The results of the multiple examination and analysis techniques previously mentioned have demonstrated that artificial stones deteriorate in a variety of ways and need maintenance and repair procedures. Future remedies that will be implemented include strengthening, cleaning, and the use of contemporary technologies to the processes of completing the missing parts of the artificial stones, among other necessary remedies.

4. Discussion

4.1. *Architectural description and photography of the building*

The building consists of three floors, and the fourth was recently constructed. In regards to architectural design and ornamentation, the building's architectural style belonged to the developed Islamic architectural style, fig. (3). It has been completely distinguished from the European architectural styles used at the time in constructing public buildings, with the aim of preserving the spirit of the place, which shall be in harmony with its intended function, which is the main headquarters of Al-Azhar Sheikh and Islamic scholars. The building is characterised by unique architectural planning, as it has five façades as follows: *The 1st façade* is the south, fig. (3-a), which is the largest in terms of extension. It entirely overlooks Al-Azhar St. It consists of two parts: The first part is a balcony for each floor. The second part consists of six longitudinal sections along the building; each section consists of three window openings with three different designs. Each floor has its own distinctive design: the first design of the first floor consists of an open window, topped with an arch buttoned up with seven voussoirs. The third design, which is the simplest, consists of an open window with a square design. *The 2nd façade* is the north-west façade, fig. (3-b), which is symmetrical in regards to the south façade. It consists of three longitudinal sections with different designs of the windows similar to those of the south façade. *The 3rd façade* is the west façade (the entrance mass), fig. (3-c), which consists of a pointed arch topped with serrated parapets. Down the vault, there is a balcony with a wall cast in Islamic geometric compositions. The stones of the entrance lead to a large gate with two shutters that opens to an internal courtyard, which leads to a marble staircase with marble stair railing. Fourth Façade: The East Façade, fig. (3-d) consists of twelve arches built on twenty-four pillars; each of these two pillars is connected to a parabolic segment to eventually form a semi-circle balcony. Entering through a staircase leads directly to the main room of the building, which is Al-Azhar Sheikh's room. Those pillars are topped with the second floor's balcony and covered with a vast, oblique canopy of clay tiles. Fifth Façade: The North Façade, fig. (3-e) overlooks the Al-Hussein Mosque. It is symmetrical to the south and south-west façades in regards to the style and models of the openings. The whole building is topped with a row of pointed parapets.

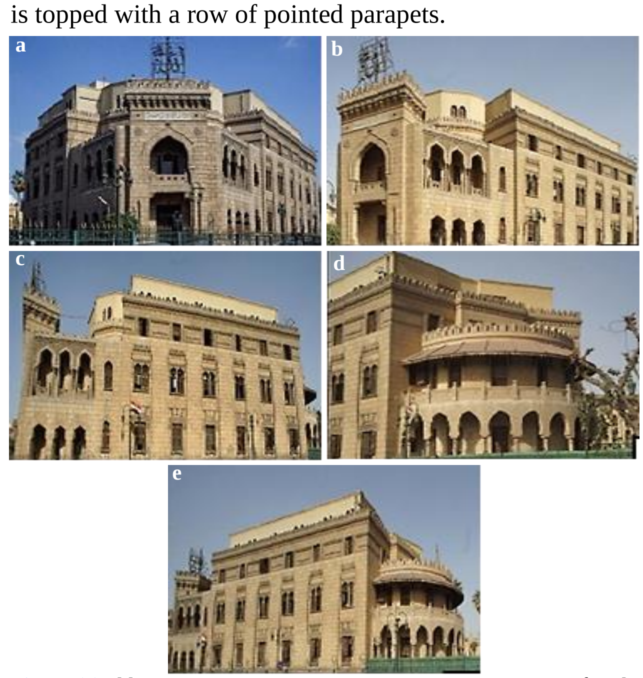


Figure (3) old headquarters building of Al-Azhar Sheikhdom; **a.** NW façade, **b.** S façade, **c.** N façade, **d.** W façade, **e.** E facade

4.2. *Engineering software in the documentation*

The External façades of the building of Al-Azhar Institute's headquarter have been drawn using the AutoCAD Software, fig. (4), at a scale of 1:100. In addition, the manifestations of damage have been illustrated and a map has been made for the damage.

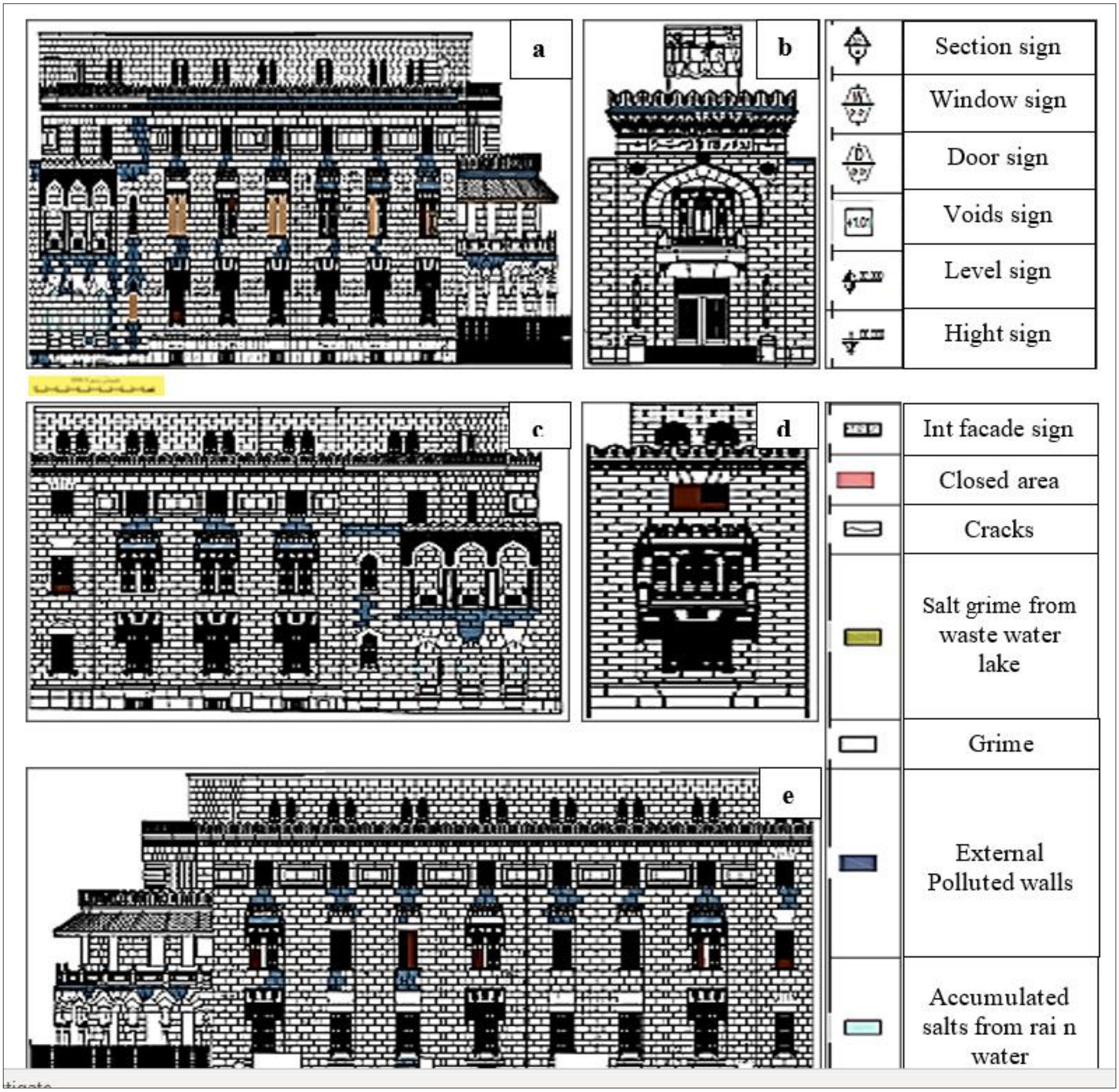


Figure (4) *AutoCAD* software in drawing the deterioration aspects in the external façades of the old headquarter of Al-Azhar Institute; **a.** Al-Azhar St., **b.** the entrance, **c.** west, **d.** north-west, **e.** north.

4.3. *Investigations and analyses*

4.3.1. Optical properties

Using USB digital light microscope is one of the important methods of scanning; as this portable microscope provides a simple method for scanning the surface texture of historic and ancient samples [21]. Using this microscope illustrate many details through scanning the artificial stones in the historic walls. Moreover, the images of this portable light microscope help the maintenance specialist evaluate the damage in historic and ancient samples [32]. Through the images obtained by the light microscope, it was found that the coarse seams, fig. (5-a & b) contain aggregate/gravel (coarse particles) in larger-size comparing to the final layer (finishing seam), fig. (5-c & d) as Ersen et al. has emphasized the same when he stated that the particles of substratum tend to be coarse; while the top-stratum tend to be more precise in size [12]. Though the images obtained for the surface layer, we can say that the outer surface is uncolored, since it was left without coloring. Furthermore, the images obtained for the substratum (coarse seam) and the top-stratum (finishing seam) indicate that the median (binder) mainly is of grey color grading, but also contains white, pink/white, yellow, light yellow and beige colors. Apparently, grey and beige colors indicate that the binding material in the samples, subject matter of study, might be cementitious. In regards with the white color, it might be hydrated or air lime, since air lime is characterized with the light colors [12]. Whereas the pink color is probably shows for using brick power, which might be added to give the pink color to the mixture. Silica particles of various sizes have apparently showed up in the images taken of the coarse substratum. Moreover, some black particles were observed; which probably due to adding charcoal or scoriae; since various materials used to be added to the mixture [12].

Figure (5) USB digital light microscope images of the artificial stones' samples; **a.** the top-stratum, **b.** the substratum

4.3.2. Petrographic properties

Through petrographic study of the artificial stones' samples taken from the old headquarter of Al-Azhar Institute using polarizing microscope, fig. (6-a), a strong and whole bonding was observed in all samples, as there were no voids between the particles; which indicates the good preparation and mixing of the artificial stones' mixtures. Through the images obtained by polarizing microscope during the petrographic study of the artificial stones' samples, it was illustrated was observed that there were two areas in the sample: the first area, (the upper area); which probably consists of quartz particles; while the other area, (the lower area), which is the coarse seams; probably consists of calcite shards (limestone). Furthermore, it was found that the dominant color of the mixture is grey. Moreover, it is apparent that the calcite particles (red arrow) are interrelated to parts of ancient fossils; while the quartz particles (yellow arrow), fig. (6-b) spread in the rest of the image; and the cement looks like a gray background contains these particles. Furthermore, it appears that the ratio of the aggregates to the binder is about 3:1 in size; as it is apparent that there is a difference in size of the calcite particles (produced by crushing limestone); as the largest size is approximately 15-16 mm). These particles are characterized by the angular shape and light grey color. In addition, existence of Qz particles (red arrow) in the cement, and the strong and whole bonding between the two essential components of the artificial stones (quartz and limestone). Furthermore, many precise cracks (red arrows) have been observed, fig. (6-c); which might be a result of the mechanical stresses to which this part of the artificial stones, from which the sample has been taken, has been exposed. There are also simple parts of clay, particularly iron, in a few millimeters, fig. (6-d); where practically iron oxides have been added to the mixtures of the artificial stones as a coloring substance to give the pink color. These findings are consistent with the findings of Colizzi et al., as iron oxides have been observed in some artificial stones samples that have been examined [33].

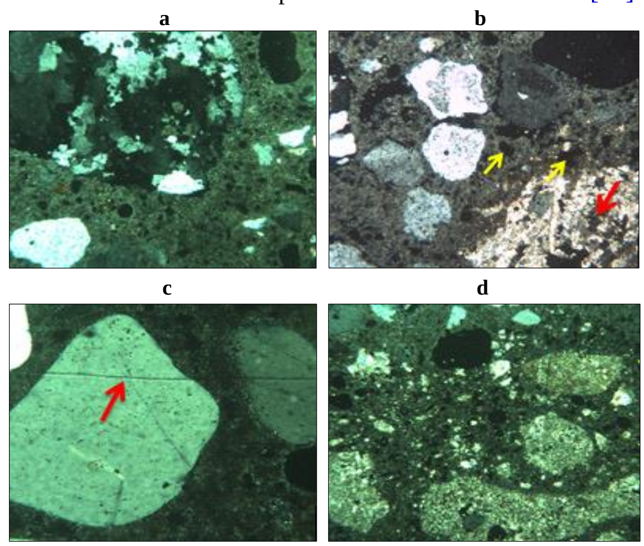


Figure (6) PM images; **a.** the composition of artificial stones seams, **b.** the percentage of limestone shards in the mixture, **c.** the strong relationship between quartz and calcite particles, **d.** existence of iron oxides, which is probably for giving the pink color.

4.3.3. Morphological features

It is considered one of the most significant modern technologies that are essential in the field of conservation and restoration in particular, and in field of archaeology in general [34]; as it gives a deep image for the morphology of the archaeological samples; and helps accurately identify the last details that help us study the constituents of the artificial stones used in the old headquarter of Al-Azhar Institute building and evaluate its current condition. Through the images obtained by using a SEM, fig. (7- a & b) calcite and silica particles have been observed. It is apparent through the images that the cement used as a binder is regular Portland cement similar to the cement produced nowadays, except for grinding; since cement used to be coarser that the current cement, due to the modern technologies available in the meantime. Lo Presti et al. [15], has emphasized that the Portland cement used in producing artificial stones is not at the same fineness degree of the Portland cement used nowadays; this is due to the modern technologies in the meantime; which work on increasing the grinding processes to produce Portland cement in extreme fineness degree. In regards with damage, a severe damage in the artificial stones sample was illustrated was observed; since cracks of different sizes have been observed, fig. (7-c & d). In Addition, remarkable severe damage, vulnerability and erosion in the mineral particles composing the artificial stones have been observed. Furthermore, the image, fig. (7-e) shows a sequence of some parasites. It is well known that parasites play a major role in the damage of artificial stones used in buildings; as they play a dangerous role in decomposition of archaeological materials and stones, due to acids and enzymes secreted by microorganism.

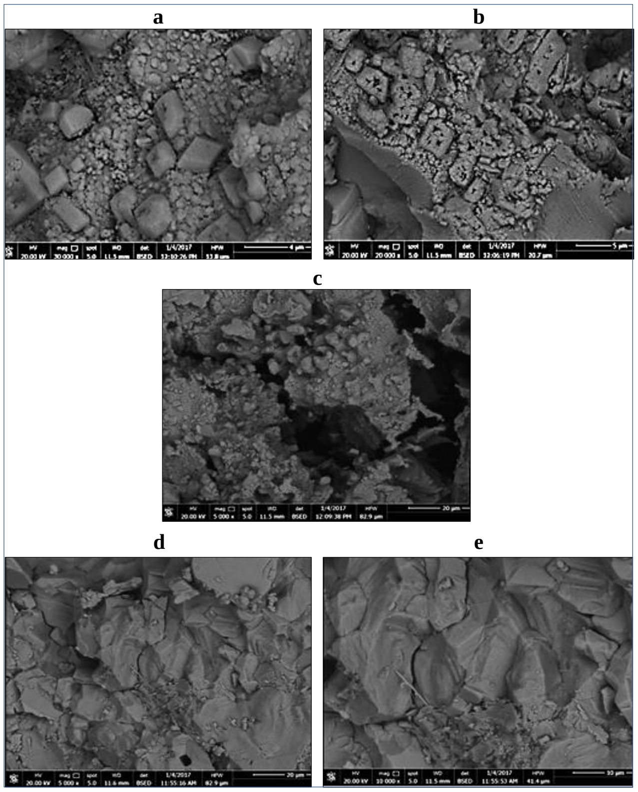


Figure (7) SEM photomicrographs of the artificial stones sample; where **a.** the coarse lower layer (red arrow), and the fine upper layer (blue arrow), **b.** calcite and quartz particles in the coarse lower seam, artificial stones sample taken from the old headquarter of Al-Azhar Institute; where **c.** decomposition in the artificial stones, **d.** cracks in different sizes in the mixture, **e.** a sequence of some parasites

4.3.4. Mineralogical composition

Through analysis using X-ray diffraction, we can determine the main substance of the aggregate included in the composition of the artificial stones' mixture; in conjunction with the petrographic findings [12]. Through the results obtained through analysis using X-ray diffraction, fig. (8), it was found that the calcium carbonates compound (calcite) is one of the basic components of the artificial stones mixture; since it is the main component which has been significantly read. Though the findings, it was found that there are many characteristic peaks of the calcium carbonates compound at (*2-Theta*): 29.7°, 38.8°, 45°; where Causin et al. has emphasized that the calcium carbonates compound are observed at 29.4˚, 39.4˚, 43.2˚ [32]; while Manso et al. has observed that the calcium carbonates compound are observed at 30° and 36° [8,35].

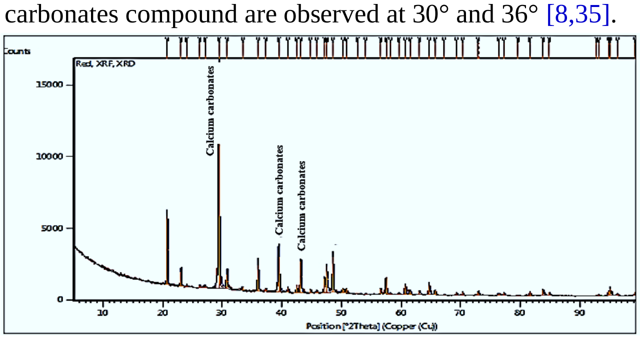
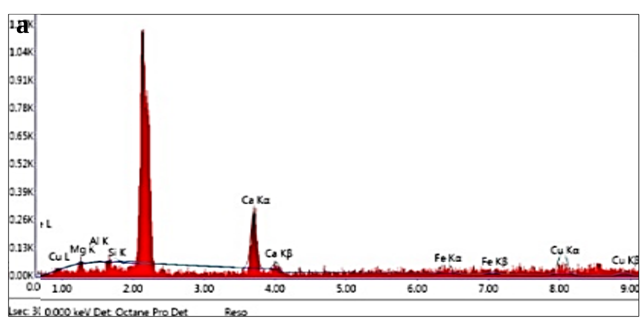


Figure (8) XRD pattern of the artificial stones sample

4.3.5. Elemental analysis using EDX

Elemental Analysis has been carried out using energy dispersive x-ray spectroscopy to identify the elements composing the artificial stones mixture, additions and contaminations. Through the findings obtained by using elemental analysis using energy dispersive X-ray spectroscopy, fig. (9) for some samples taken from the façades of the old headquarter of Al-Azhar Institute, it was found that the binding material consists of a high percentage of calcium, silica and a few amounts of Aluminum; which indicates the existence of calcium silicate, which is commercially known as (white Portland cement), which is hydraulic. It is worth noting that when white Portland cement interacts with water, it produces calcium silicate hydrate, which is a nano-sized substance; since this plays a major role in the strength of mechanical binding between the molecules of artificial stones. In addition, this substance is characterized by being amorphous; thus, it cannot be observed in the analysis using elemental analysis using energy dispersive X-ray spectroscopy. These findings are consistent with the findings of Ersen et al. [12]; who stated that the high percentage of calcium and silica is an evident of using calcium silicate. In regards with the aggregates, it was found that they consist of a high percentage of calcium; which indicates the existence of milestone ($CaCO_3$), (this has been also observed through petrographic study and analysis using XRD. It was also observed the existence of Aluminum in varying degrees (0.70%, 0.71%, 1.21%, 3.59%); which indicates the existence of the Kaolin substance ($Al_4Si_4O_{10}(OH)_8$) in the artificial stones' samples taken from the old headquarter of Al-Azhar Institute. In addition, EDX results, indicate the existence of Iron element (1.91%, 7.8%, 13.3%, 16.45%); since its existence is due to adding iron oxide (Red) in order to give the red color to the artificial stones mixture. It is apparent that the findings confirm the findings obtained through the polarizing microscope; through which the mineral of iron, that was added to give the mixture the pink red color, was observed [36]. Furthermore, by referring back to the findings of the elemental analysis, it was found the cement mixture contained Magnesium (4.44%, 6.54%, 13,27%); which might be resulted from its existence with the minerals attached to the limestone (calcite). By referring back to the previous studies, it was found that this result is consistent with the findings of Lo Presti et al., who emphasized that the existence of Magnesium in the artificial stones mixture is due to being used as attached minerals to the limestone [15].



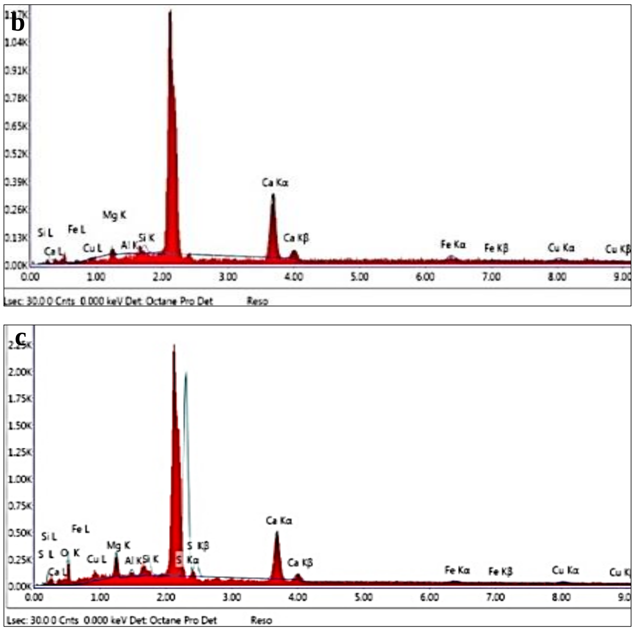


Figure (9) EDX patterns of the artificial stones' samples taken from the old headquarter of Al-Azhar Institute; **a.** 1st sample, **b.** 2nd sample, **c.** 3rd sample.

4.3.6. Elemental analysis using pXRF

Through the findings obtained using pXRF, fig. (10) it was found that the artificial stones sample mainly consists of Ca at percentage of 54.2%, Si at percentage of 2.5%, and a small percentage of Al at 0.6%; which indicates the existence of calcium silicate; which is the main component of the Portland cement used as a binder for the artificial stones mixture. Moreover, the existence of Fe was observed at a percentage of 1.8%; which might indicate using iron oxides to give the mixture the red color. Furthermore, the existence of Mg was observed at a percentage of 1.3%; which might be resulted from being used as attached minerals to the limestone.

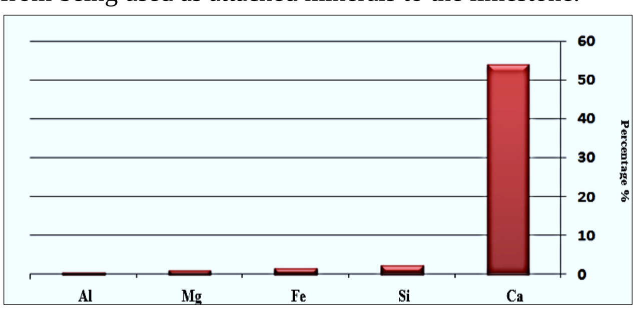


Figure (10) pXRF elements composing artificial stones

5. Conclusion

Various tests and analyzes were carried out to diagnose the components of the artificial stones used in the old headquarters of the Al-Azhar Sheikhdom, in addition to assessing the condition of the artificial stones used in the external facades of the building of the old headquarters of the Al-Azhar Sheikhdom. Important information has been obtained through the results of the tests and analyzes used. Through examinations and analyzes of samples taken from damaged and deteriorating artificial stone from the old headquarters of the Al-Azhar sheikhdom, and studying thin sections of the prepared samples, it was found that the binding material is industrial Portland cement. As for the aggregate, the aggregate is smaller in size and usually lighter in color, such as white sand, crushed (powdered) limestone. Through a petrographic study using a polarizing microscope, the approximate ratio of the binder (mediator) and the aggregate used was determined, which is approximately 3:1. Strong overall bonding was observed in all samples, as there are no spaces or voids between the grains, which indicates good preparation and mixing of the artificial stone mixtures. Moreover, the images obtained from the scanning electron microscope showed that the artificial stones in the building under study suffer from many signs of damage and deterioration, such as cracks of different sizes, damage and corrosion of the mineral grains that make up the artificial stone samples. The results confirmed the need to carry out the necessary treatments, especially the strengthening process, to preserve these artificial stones in the building under study. The results of the various methods of tests and analyzes mentioned above have proven that artificial stones suffer from many deteriorations and require restoration and maintenance operations. Future treatment operations include cleaning, strengthening, applying modern technologies in the process of completing missing parts of artificial stone, and other treatments as needed.

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