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Original article

CORROSION CHARACTERISTICS AND CONSERVATION OF ANCIENT EGYPTIAN BRONZE OSIRIS STATUETTE FROM AL-ARISH MUSEUM

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Abstract:
A bronze statuette in the form of Osiris is dating back to the late period. It was manufactured by casting method. The statuette in the Osiris position shows the wand, the sceptre and the royal crown and has a cobra snake. The hooked chin and facial details reveal a calm smile. On the outside, the statuette suffered from deterioration phenomena, for example different layers of soil mixed with sand and corrosion products on the statuette's surface. Bronze disease appears in separate areas of the statuette. Various examinations and analyses were performed on the samples that represent the places of damage on the statuette. The layers on the statuette surface were studied using stereo microscope examination, polarizing microscope and scanning electron microscope with energy dispersive X-ray analysis (SEM-EDX). Examinations show that the surface layers consist of clay minerals, sand and corrosion products in various colors. The mineral composition of the samples was determined by X-ray diffraction analysis. The analysis revealed the presence of cuprite, atacamite as Corrosion products, in addition to quartz. Calcifications have been removed using appropriate tools such brushes and blunt scalpels. Treatment processes of the bronze statuette include mechanical and chemical cleaning in addition to apply benzotriazole inhibitor by 3%. A protective layer of paraloid B 82 by 3% was applied. Finally, the bronze statuette was displayed in Al- Arish museum.

1. Introduction

Al-Arish Museum contains many bronze objects dating back to the Late period. An example of this is a Bronze Oserian statuette, inscribed with number (1353), made of bronze on a wooden base. This statuette was formed by casting method, which is a hot forming method, This was verified by examining the statue as well as its weight, which indicates that it is solid [1]. The simplest example of the casting process is the placement of molten metal in molds carved in the stone or pottery or sand [2]. There are more complex molds that are used to produce statuettes, such as this bronze statuette, and these molds consist of two, three or more parts, so that we can get the statuette that was cast [3]. In the lost wax casting process, the required model is made in the form of a mold of wax or some other material, in which you can easily form the statuette. Beeswax or mixtures of oil with resin or wax with resin were used [4]. After that, the wax model is covered with a layer of clay with the addition of an organic material such as animal dung or hay, [5] and a hole is made in the bottom of the outer surface of the statuette that was formed, where a burning process is then carried out for the clay model, and the burning heat results in the melting of the wax that makes up the inner statuette and exits from the bottom hole, [6] then the molten metal is placed inside the model and after the cooling and drying processes are completed, the mold is broken to extract the statuette that was cast [7]. The sandy soil in which the statuette was, discovered [8] has a strong and essential role in the corrosion compounds that formed on the statuette. Because sandy soil forms a structure with wide and multiple pores through which air and water solutions pass in an irregular way, but it is easy and continuous as long as there is a continuous tide of these components, fig. (1) [9]. As a result of the relatively small specific surface and semi-inert composition due to the presence of silica as a basic component, this type of soil is considered inactive in itself in chemical or electrical reactions, but it acts as a structural factor to bind the active components in the corrosion process and its distribution on a continuous basis, which makes it considered one of the most dangerous types of soil for buried mineral monuments, if some active components of salt ions and gases are available [10]. This research aims to study corrosion compounds and to know the environment, from which the statuette was extracted, the effects of this environment on the formation and quality of corrosion compounds as well , carry out treatment and conservation processes to preserve this statuette from deterioration again and protect it from the further corrosive factors surrounding it.

Figure (1) Shows bronze Osiris statuette, covered with corrosion layers mixed with soil.

2. Materials and Methods

There are heterogeneous layers of different components on the surface of the statuette and no maintenance or removal of the statuette has been carried out since the time of its discovery from the excavations because the statue was preserved after its discovery in a warehouse for many years. Samples were taken from the surface of the bronze statuette for examination and analysis. Samples of the statuette were examined using a stereomicroscope to identify the nature of the components on the surface of the statuette. Leica S9i, Stereozoom microscope was used with zoom magnification changer for incident light with integrated MC190 HD 10MP full HD digital video camera system. The polarizing microscope was used to examine microscopic thin sections to identify the metal components on the surface of the statuette, whether corrosion products or components from the soil. Leica DM750P LED, Trinocular polarizing microscope for transmitted light bright field with infinity optics was used in investigating the thin section samples. The analysis was used with the EDX unit attached to SEM to identify the elements in the samples taken from the surface of the statuette. SEM micrographs and EDX spectra of the selected samples were obtained using a JSM-6380 LA instrument equipped with a Link EDS operating up to 30 kV. X-ray diffraction analysis was used to identify the compounds on the surface of the statuette, which are the components of the soil mixed with corrosion compounds. X-ray diffractometer model Philips PW1840 was used.

3. Results

3.1. *Stereo microscope examination*

The bronze statuette examined samples turns out that there are layers of corrosion distributed unevenly and irregularly mixed with soil components. Some of these layers are thin and some are thick. Also, some of them are in a fine powder and the others in solid case. A layer of corrosion appeared in reddish-brown colour. Layers of chalky green and green also appeared, fig. (2).

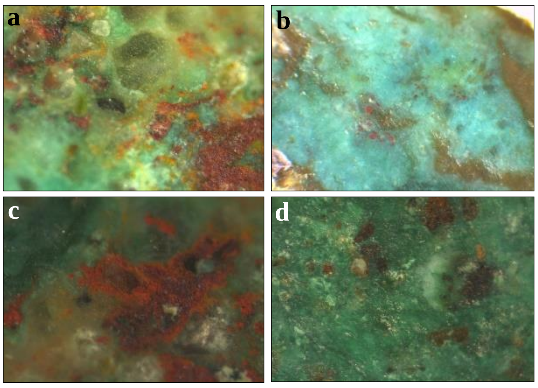

Figure (2) Shows stereo-microscope images; **a.** grains of quartz mineral and soil mixed with corrosion compounds, **b.** corrosion products in different colours including green and chalk green, **c.** the presence of corrosion layers adhered to the surface of the statuette, **d.** a thick, shiny layer of corrosion compounds.

3.2. *Polarizing microscope examination*

Thin sections of the surface layers adhered examined by polarizing microscope revealed an overlap between layers of soil and bronze corrosion components. The presence of quartz gran-ules, the main component of sand in the soil, in addition to iron oxides and granules of clay minerals were detected. The previous ingredients mixed with bronze corrosion products that appeared in red-brown, green and chalky green colours. It is clear that, the bronze statuette, after it was discovered in excavations and extracted from the soil, kept soil components on the surface, fig. (3)

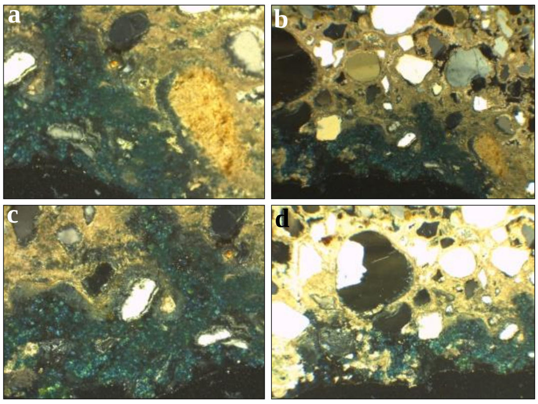

Figure (3) Shows PLM images; **a.** the components of the heterogeneous layers on the surface, **b.** corrosion compounds with quartz grains and clay minerals, **c.** bronze corrosion compounds as well as iron oxides found in the soil components, **d.** mixing of corrosion products with soil particles of different sizes.

3.3. *Scanning electron microscope (SEM) examination*

The surface layers adhered to the bronze statuette examined using SEM showed the extent of their homogeneity or heterogeneity, the size of the grains and the state of their crystals, especially salt and soil crystals, clay minerals and iron oxides, in addition to the components of bronze corrosion products, fig. (4).

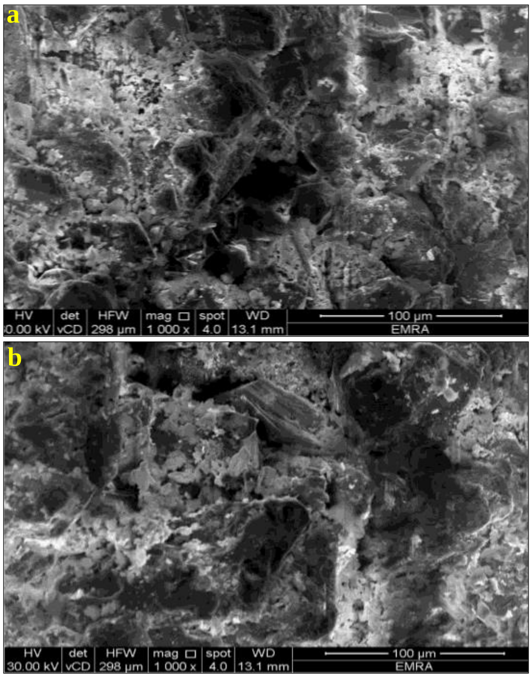

Figure (4) Shows **a.** corrosion layers cracks and voids, **b.** heterogeneity of the layers adhered to the surface of the statuette.

3.4. *Elemental analysis by EDX*

The samples surface components analyzed by EDX) proved that, the presence of 24.25 % Cu, 20.46 Si, 4.44 % Ca, 0.54 % Sn, 5.97Cl, 29.39 O, 12.47 C. Ratios of elements have been found and the results are complete, fig. (5).

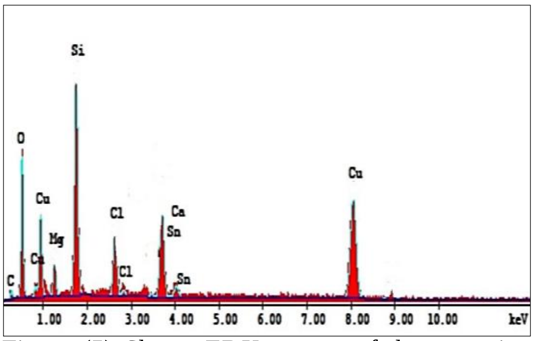

Figure (5) Shows EDX pattern of the corrosion products sample

3.5. *Mineralogical analysis by XRD*

Due to the similarity of the corrosion samples analyzed by XRD, one of them was placed in this research. The resulted data shows the presence of the cuprite (Cu_2O), in addition, to atacamite ($Cu_2Cl(OH)_3$) that explaining the presence of chlorine ions in the soil, also quartz mineral that indicates that the soil where this statuette was disc-overed is sandy soil, fig. (6).

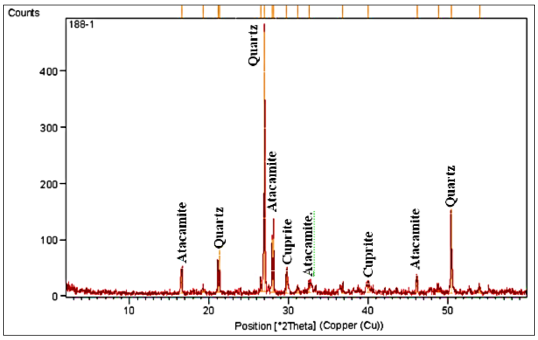

Fig (6) Shows XRD pattern of the sample corrosion products.

4. Discussion

The condition of the statuette required various conservation processes to prepare it for displaying in Al-Arish Museum. Before the treatment processes of the statuette, various examinations and analyzes were carried out in order to identify the layers adhered to the surface of the statuette. It was clear from the examinations using a stereomicroscope that, the presence of surface layers with different colors, [11] including light green, reddish-brown mixed with grains of sand and other calcified materials [12]. Furthermore, the presence of heterogeneous corrosion layers mixed with each other. In addition the presence quartz and some clay materials explain the different components that characterized the excavation area of this statuette [13] composed of sandy soil [14]. This result was also confirmed by SEM results [15]. Moreover, the investigation revealed the heterogeneity of the surface corrosion layers of the statuette and partly presence of voids and cavities [16]. Presence of copper and tin through EDX analysis is essentially due to the bronze alloy that made up the statuette, [17]. On the other hand, the presence of oxygen, calcium, iron and chlorine are owed to different materials and salt ions in excavation area [18]. The most important of them is chlorine ion attributed to the presence of halite salts characterized Egyptian soil [19]. This explains that the statuette had been exposed to the effects of two main environments; buried soil (*before excavation*) and open air (*after excavation*) presence of the statuette buried in the soil and its discovery in excavations [20,21]. It was clear from the analysis by X-ray diffraction that cuprite was present as a result of the presence of the oxygen element, which led to the formation of copper oxide (the chemical structure of cuprite mineral) [22]. Atacamite mineral was also found which consists of copper chloride due to the presence of chlorine ions in the soil [23]. It appeared in chalky green color and is known as bronze disease. Furthermore, the presence of quartz is due to the presence of the statue buried in soil contains sand as one of its basic components [24].

5. Conservation Processes of Osiris Bronze Statuette

Based on the previous results, different treatment and conservation procedures of the bronze statuette were carried out according to the following steeps.

4.1. *Mechanical cleaning*

Different types of soft brushes were used for avoiding the scratching the statuette surface and, maintains the original patina layer [25]. These types of brushes were used according to the thickness of the corrosion layer. Blunt scalpels and wooden spatula were used parallel to the surface of the bronze statuette [26]. Milling machine was used in hard and thickest areas of the corrosion layers. This was done for places of bends which were found in the parts of the bronze statuette and was done parallel to the surface of the statuette, So that the patina layer is not affected by the treatment processes [27], and the original view of the statuette was preserved.

4.2. *Chemical cleaning*

Rochelle salt solution was selected for chemical cleaning of the bronze statuette Because it is suitable for removing corrosion compounds, It is prepared by adding (30) gm of caustic soda into (250) cm^3 distilled water, then (90) gm of sodium and potassium tartrate is dissolved in (750) cm^3 distilled water. The two solutions are mixed together to create one litre of Rochelle salt [28]. It was applied by the method of poultice. Cotton was used to remove layers of corrosion, where the cotton is placed on the corrosion layer after saturating the cotton with a solution of Rochelle salt. Bronze disease areas on the surface of the bronze statuette were treated with a 5% dilute solution from a compound consisting of carbonate and sodium bicarbonate (Sesqui Sodium Carbonate) Na_2CO_3+$NaHCO_3$, and this is in a 1:1 ratio. Then any residue from the chemical cleaning was removed using distilled water [29]. For soils deposits, Sodium hexaphosphate solution with 5% concentration was used.

4.3. *Isolate the statuette*

The bronze statuette was treated using benzotriazole by 3 % in acetone [30] and was isolated by using paraloid B 82 3% in toluene to protect it from deterioration and after the completion of treatment processes, it was displayed in the Museum, fig. (7).

Figure (7) Shows the Osiris bronze statuette after conservation processes.

6. Conclusion

There are many bronze statuettes discovered in the form of the god Osiris. These statuettes illustrate the ingenuity of the ancient Egyptians in sculpting, shaping, and making bronze statuettes. The type of soil in which the statuette was discovered identified through examinations, especially using a polarizing microscope. Examination revealed that the soil in which the statuette was discovered is sandy. The presence of soil grains and quartz mineral mixed with bronze corrosion compounds caused the heterogeneity of the components on the surface of the statuette despite the presence of a homogeneous layer of cuprite beneath it. In the Egyptian soil, there are saline impurities of the halite mineral, which is a source of the element chloride, which leads to the formation of the bronze disease. It was confirmed by the analysis by XRD, where the mineral atacamite appeared in addition to quartz related to the sandy soil. The treatment and conservation processes of the statuette were carried out to prepare it for museum display in the Al-Arish Museum by mechanical and chemical cleaning and removing the heterogeneous layers from the surface while preserving the homogeneous layer of cuprite. The surface of the statuette was treated with benzotriazole at a concentration of 3% as a corrosion inhibitor. A protective layer was applied to the surface of the statuette using paraloid-B82. Finally, the statue was displayed in the Al-Arish Museum.

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