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MANUFACTURING, DETERIORATION, AND CONSERVATION TECHNIQUES OF NEFERTUM BRONZE STATUE FROM THE LATE PERIOD DISCOVERED IN THE MEMPHIS NECROPOLIS, EGYPT.

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Abstract:
The bronze Nefertum statue is one of the statues discovered by the Egyptian archaeological mission at Minf Cemetery of the late period in 2020, during the performance of the excavation work dates back to the late 26th dynasty. The statue with its base is 41 cm high, 35 centimetres tall and 7 cm wide and 14 cm deep. The name of its owner Badi Amunis engraved on its base. Badi Amun is from the 26th dynasty. The statue suffered from deterioration phenomena, for example, Erosion parts, corrosion products, Micro-cracks, Dirt and calcifications. Various examinations and analyses were carried out. The layers on the Statue surface were studied using stereo microscope examination, polarizing microscope and scanning electron microscope (SEM) with energy dispersive x-ray analysis (EDX). Examinations show that the surface layers consist of clay minerals, sand and corrosion products in various colours. 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 Statue 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 Statue was displayed in Museum of the New Administrative Capital in Egypt.

1. Introduction

The Egyptian archaeological mission working in the Saqqara, 3, 0 km south of Cairo, discovered a bronze Statue of the god Nefertum, fig. (1). The Saqqara archaeological area is an open book whose pages tell the story of Egyptian civilization across its various ages. It is the only cowardly in all Egypt that includes cemeteries from the beginning to the end of Egyptian history [1] Saqqara is located south of the pyramids, part of the Minf area from Abu Rawash north to Maidom south. Saqqara has about 30 pyramids. So, it is the encyclopaedia of Egyptian antiquities of history and art. Saqqara, west of the Nile, is located 28 km south of the city of Cairo between the two lines of 30 29: 0:30 AM North and between the lines of 0:31 AM: 10 31 am [2]. East covers an area close to 183 km^2 long and one mile wide, bordered from the north by the pyramid Plateau and from the south by the Abu Sair Plateau, and bordered from the east by the Nile River and from the west and as a natural extension of the west Saqqara Plateau, stretching west with the desert of western Egypt. There are four important elements for determining an area's climate and its impact on its surface formation: rain, moisture, wind and heat [3]. The Saqqara area is generally located in the northern tip of the Central Climate Region of Egypt, which is characterized by the extreme desert climate with little rain and the number of falls and according to the climate data of the Egyptian Meteorological Authority The highest rainfall over the past 50 years in Cairo was always in December, averaging 6.3 millimetres/month, and the average number of days of rainfall in this month was 2.9 days, while the lowest rainfall in June was 0.1 millimetres/month, August and September have no rain at all [4]. Although rain falls somewhat rare in the Saqqara region, when it falls, it is heavy in the form of Seoul, but in general, the few amounts of rain that often fall in winter contribute to the dissolution of limestone. The moisture in the air also contributes to the activation of chemical ventilation processes; the relatively low winter evaporative values contribute to the increased retention of rainwater by rocks and archaeological building stones, especially rocks and porous stones, facilitating the migration of water and rain to other rocks. This is in addition to the high humidity in summer and autumn and the leakage of dew droplets to sedimentary layers. Saqqara is characterized by a large thermal range, which is the difference between the bone end and the exact end of temperatures and is 10.2 degrees Celsius due to its presence within desert territory. There are two types of thermal range. The first is the daily temperature range, which is the difference between large and partial ends of the temperature during the day. Second, the annual temperature range is far from the difference between the average highest temperatures during the year's months. According to the same data, the highest average temperature during the previous period was in July, where the average end of bones was 34.7 degrees Celsius and the average temperature in January at the end of bones was 18.8 degrees Celsius. The average small finish was 8.9 degrees Celsius. Moisture is the most important climatic element of all time its composition significantly controls its permeability for moisture and rainwater. Permeability is more in the direction than in the vertical direction depending on the direction of the layers [5]. Meteorological Authority climate data indicate that the highest relative humidity level over the past 50 years in Cairo was during November and reached about 61%, while the lowest average in May and around 44%. January, August, September and December led to relative moisture rates, which appear to be modest within the Earth buildings 59% Dangerous if we know that fungi growth on wall photo surfaces starts when relative humidity is 65%. The new capital museum was located in the City of Arts and Culture in Egypt's new administrative capital. The museum showcases shed the light on the story of Egyptian capitals and their development throughout Egypt's history from its oldest capital, Memphis, to its newest capital. The museum is unique in Egypt, focusing mainly on Egyptian capitals. The statue was manufactured by casting [6]. The simplest example of the casting process is the use of a method known as "lost wax." [7]. In this method, the model that is poured from the wax is formed and then covered with suitable material from the clay or mixed with sand and lime [8] and then immersed in hot sand where the entire mass is heated [9], the wax dissolves and the outer mould becomes solid [10]. Wax is getting out from its hole, especially prepared, then the bottom hole is blocked and the mould is prepared for the statue forming process and then becomes inside the forming process [11]. In the same way, gold, silver and solid bronze statues were made [12]. The sandy soil in which the statue was discovered is a complex structure with multiple pores through which air and aqueous solutions pass in an irregular but easy and continuous manner. As long as there is a constant tide of these ingredients, sand soil is one of the most dangerous types of soil on metallic antiquities spread or buried if there are some active components of ions that are different corrosion compounds depending on ions and salts available in the soil. This research aims to study the burial environment of the statue, to know the effect of this environment through the quality of the corrosion compounds formed on the surface of the statue. Develop a plan to restore, treat and protect this statue from damage again.

Figure (1) **a.** the bronze statue of Nefertum, **b.**, **c.**, **d.** details of the bronze statue of Nefertum.

2. Materials and Methods

AutoCAD program *2024 version* was used to record the Nefertum statue in drawing before and after sinning the deterioration symptom. Samples of the statue were examined using a *stereomicroscope. Leica S9i*, Stereozoom microscope with magnification changer for incident light with integrated MC 190 HD 10MP full HD digital video camera system was used. *Leica DM750P LED, Trinocular polarizing microscope* for transmitted light brightfield with infinity optics was used to examine thin sections samples to identify the corrosion products which mixed with the components of the soil. *JSM-6380 LA equipped with a Link EDX operating up to 30 attached to* was adapted to identify the elements of the samples taken from the surface of the statue. PW3040/60 X-ray diffraction *(XRD)* – Analytical Equipment – PANalytical pro model with a Cu anode, working at 40mA/45kV) was used to identify the compounds on the surface of the statue, which are the components of the soil mixed with corrosion compounds.

3. Results

3.1. *Computerized documentation using AutoCAD program*

The drawing by *AutoCAD* program indicating the signs of deterioration phenomena on its surface, including corrosion products, corroded parts, and adhered dirt, fig. (2).

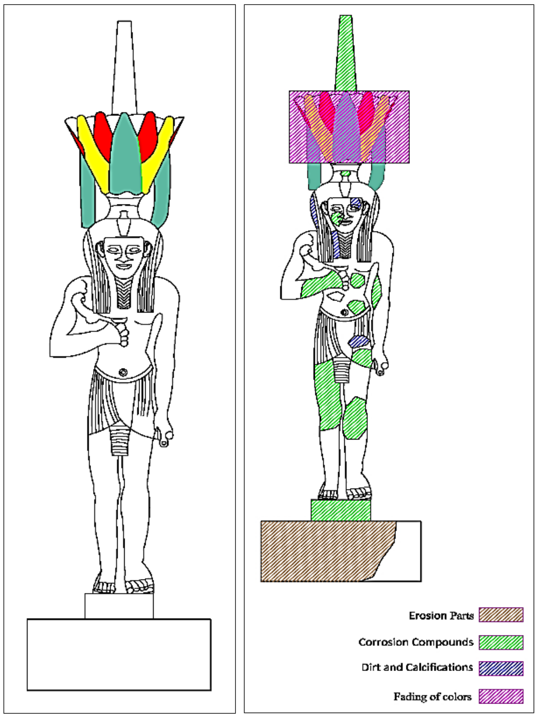


Figure (2) *AutoCAD* documentation of **a.** Nefertum bronze statue using, **b.** the deterioration phenomena affected the statue

3.2. *Stereo microscope results*

Stereo microscope investigation 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. (3).

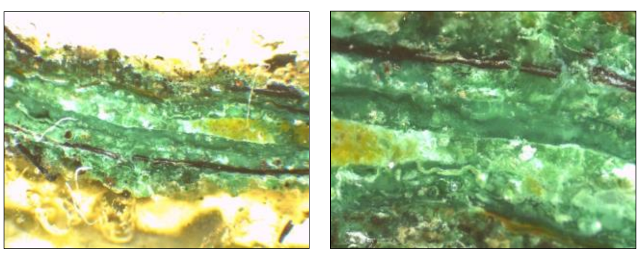


Figure (3) stereomicroscope images show the presence of corrosion layers adhered to the surface of the statue and appear in different colours including green, chalk green, and reddish-brown, in addition to the grains of quartz mineral and soil mixed with corrosion compounds.

3.3. *Polarizing microscope results*

Examination of thin sections of the surface layers adhered revealed an overlap between layers of soil and bronze corrosion components. The presence of quartz granules, 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 shown that, the bronze Statue, after it was discovered in excavations and extracted from the soil, kept soil components on the surface, fig. (4).

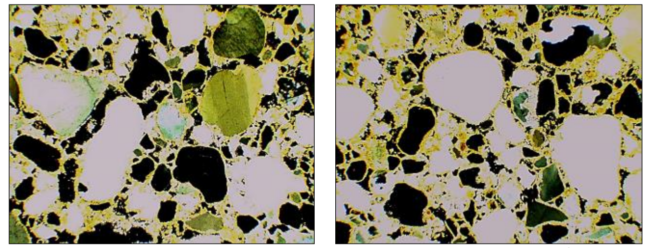


Figure (4) polarized microscope images show the components of the heterogeneous layers on the surface, which include bronze corrosion compounds with quartz grains and clay minerals, as well as iron oxides and salts found in the soil components.

3.4. *SEM-EDX results*

Samples of the surface layers adhered to the bronze statue examined by scanning electron microscope to identify their different morphological and surface characteristics, revealed the extent of their heterogeneity in 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. (5-a & b). Samples from the surface components of the statue analyzed by EDX attached to the scanning SEM showed that the presence of Cu 24.25 %, Si 20.46, Ca 4.44 %, Sn 0.54 %, Cl 5.97, O 29.39, C 12.47, fig. (5-c: f).

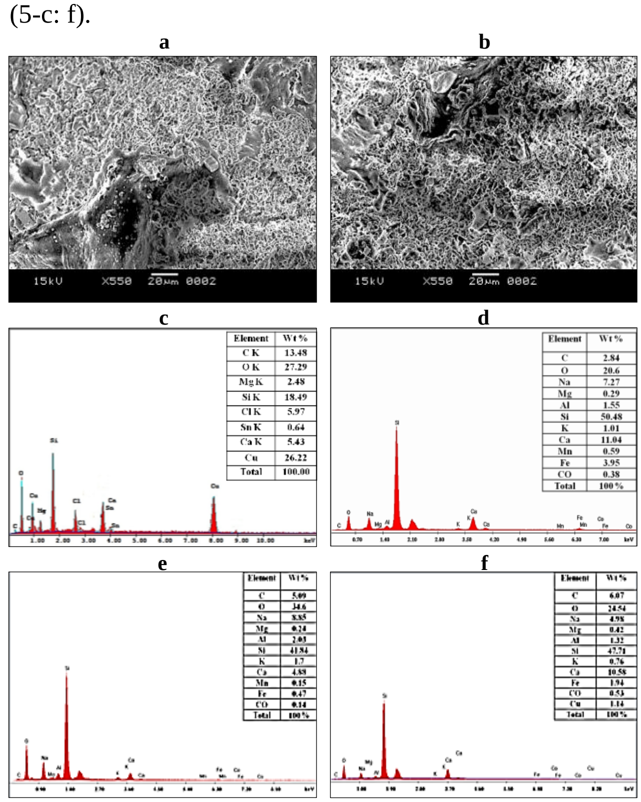
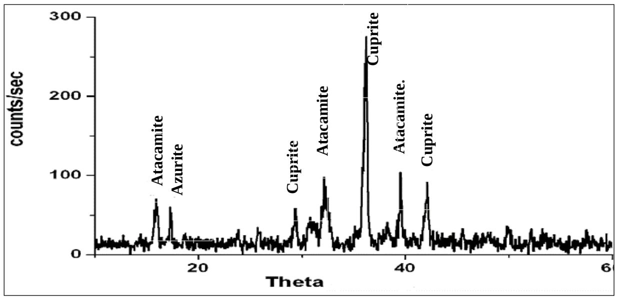


Figure (5) **a.** & **b.** SEM photomicrographs show heterogeneity of the layers adhered to the surface of the statue, cracks, gaps, EDX patterns of the **c.** corrosion products sample, **d.** red glass paste, **e.** yellow glass paste, **f.** green glass paste used to inlay the crown of the statue of Nefertum

3.5. *XRD results*

A group of samples was analyzed by X-ray diffraction to identify the statue rust compounds and due to their similarity; one of them was placed in the research. X-ray analysis of corrosion compounds shows the presence of the cuprite (Cu_2O), malachite [$Cu_2CO_3(OH)_2$], azurite [$Cu_3(OH)_2(CO_3)_2$], tenorite (CuO) in addition to atacamite $Cu_2Cl(OH)_3$ explaining the presence of chlorine ions in the soil, also quartz (SiO_2) mineral that indicates that the soil where this Statue was discovered is sandy soil, fig. (6-a & b) & tab. (1).

a



b

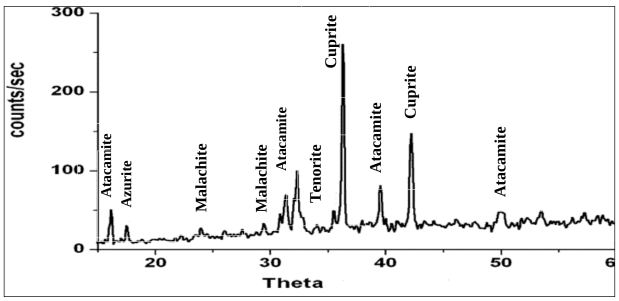


Figure (6) XRD patterns of corrosion products samples.

Table (1) XRD analytical results of corrosion products of the statue samples

Sample No.	Sample type	Compounds	Chemical composition
a	Corrosion products	Cuprite	Cu_2O
		Azurite	$Cu_3(OH)_2(CO_3)_2$
		Atacamite	$Cu_2Cl(OH)_3$
b	Corrosion products	Malachite	$Cu_2CO_3(OH)_2$
		Tenorite	CuO
		Cuprite	Cu_2O
		Azurite	$Cu_3(OH)_2(CO_3)_2$
		Atacamite	$Cu_2Cl(OH)_3$

4. Discussion

Examinations and analyses were carried out to identify the components of the statue of Nefertum and to study the deterioration found in it, in order to determine the treatment and conservation plan for the statue. Examinations were performed using a stereo microscope, a polarizing microscope, and SEM. Examination with a stereomicroscope revealed the presence of layers of green, chalky green and reddish-brown of corrosion compounds, topped with layers of burial soil components, with corrosion on the surface of the metal [13]. Examination with a polarizing microscope of the soil attached to the surface of the statue revealed the presence of sand grains (quartz mineral) of various sizes and shapes mixed with soil minerals, the most important of which are clay minerals. This porous soil contributed to the solutions present in the soil reaching the surface of the statue, which led to it being exposed to corrosion [14]. The glass pasts in the crown of the statue were also exposed to parts of it corroding, other parts being lost, roughness appearing in parts of its surface, and various cracks on the surface [15]. It became clear from examination with scanning electron microscope of the layers of soil components and corrosion products adhered to the surface of the statue that they were mixed and heterogeneous and interspersed with pores and gaps that contributed greatly to the statue's exposure to deterioration [16]. This result was also confirmed, as we mentioned, through examination with a stereomicroscope and a polarizing microscope. It became clear from analyses with the EDX unit attached to the scanning electron microscope of a sample of the statue representing its components and the layers attached to a surface of burial soil that the statue is bronze, as copper was found in the sample at a percentage of 22.26 and tin was found at a percentage of 0.64 [17]. The presence of carbon at a rate of 13.48, oxygen at a rate of 27.29, and the element copper indicates the presence of carbonate copper corrosion compounds represented by malachite and azurite [18]. This result was confirmed through analysis by X-ray diffraction. Also, the presence of oxygen and copper indicates the presence of copper corrosion compounds from oxides, represented by cuprite and tenorite. These minerals appeared in the X-ray diffraction analysis as well [19]. The sample also contained silicon in a ratio of 18.49, which indicates the presence of sand among the adhered soil components. In addition, the magnesium element was found on the surface of the statue, with a ratio of 2.48 [20]. The calcium element is 5.43, which indicates the components of the statue's burial soil. The ancient Egyptian used inlaying with colored glass pastes of different colors, including blue, red, yellow, and green, to imitate precious stones such as: lapis, lazuli and agate. We find that there is erosion on the edges of the glass pastes that the ancient Egyptian used in inlaying the bronze statue of Nefertum, which indicates that they are not natural gemstones because natural gemstones resist damage and errosion by the burial environment surrounding the statue. It also became clear from analyzes at the EDX unit of samples of glass pastes in the statue's crown that the iron element present at a ratio of 3.95 is the source of the red color and the yellow color, as it was found in the yellow glass paste at a ratio of 0.47. It was also shown that the presence of copper at a ratio of 1.14 and iron at a ratio of 1.94 are the sources of the green color in glass pastes [21]. Analysis using X-ray diffraction of samples of corrosion compounds present on the surface of the statue showed that they contain the minerals cuprite and tenorite, which represent copper oxides, as well as carbonate copper corrosion minerals, represented by the malachite and azurite minerals. There is also the presence of the atacamite mineral, which is a compound of copper chlorides, known as bronze disease [22] which is formed as a result of the presence of chloride ions [23] Chlorides are mostly sodium chloride salts found in burial soil [24]. Analysis using the EDX unit attached to a scanning electron microscope confirmed the presence of the elements that make up these minerals, which represent corrosion compounds on the surface of the statue.

5. Conservation Processes of the Statue

Treatment and conservation of the Nefertum statue included mechanical and chemical cleaning. Mechanical cleaning was started, which is the safe method that does not cause chemical changes to the antiquities. The mechanical cleaning process is appropriate for the condition of the Nefertum statue, as its condition is solid and its surface is topped with a layer of soil residue mixed with sand. There are also some corrosion products on the surface of the statue that are green, chalky green, blue, black, and reddish brown of the minerals malachite, atacamite, azurite, tenorite, and cuprite. Hand tools of different shapes were used, including thin, pointed steel needles, small chisels, and metal pens, in addition to brushes of different sizes and shapes made of nylon brushes and coarse brushes, they were used carefully and carefully to remove the layers of soil, sand, and rust compounds adhering to the surface of the statue. Mechanical methods gave a good result in cleaning the statue [25]. They were used with great care in the crown area of the statue. As for the glass pastes, mechanical cleaning was done using fiberglass brushes accompanied by appropriate magnifying lenses and with great care [26] as it gave a good effect in cleaning dirt and is suitable for use in the case of weak parts. For chemical cleaning of the crown inlaid with glass pastes, distilled water was used, and organic solutions and solvents, ethyl alcohol and acetone, were used. The glass pastes were strengthened using a solution of Paraloid B-72 dissolved in toluene at a concentration of 30%, using a soft brush on the glass surface in weak areas and cracks. Chemical cleaning of the statue was carried out using a 5% solution of sodium sesquicarbonate in water in order to remove the chlorides represented by the atacamite mineral. Local reduction was also used to remove the remains of compounds or chloride pitting (bronze disease) by using a solution of 5% citric acid with water locally with zinc powder [27]. A 3% solution of benzotriazole with water was used as a corrosion inhibitor [28] the statue and to isolate it from external deterioration factors [29]. Methods for displaying metal antiquities require a stable environment in which the relative humidity does not exceed (45% to 55%) and the temperature does not exceed (20 degrees Celsius). Humidity-sensitive devices can be used to give signals to operate devices that raise or lower the humidity. An increase in relative humidity beyond this limit exposes the metallic effect of corrosion. Changes in relative humidity also accelerate the corrosion process and increase its effectiveness. A moisture-absorbing material (silica gel) is placed inside the museum display cabinets to absorb any relative humidity that seeps into it. The museum display rooms are well closed so that atmospheric pollutants do not seep into them. Appropriate light sources are chosen for museum display so that the light is sufficient to show the statue's archaeological, historical, and aesthetic artistic values [30]. It is (300 lux) and ultraviolet rays (75 microwatts/lumen). Plexiglass was used in making the museum display of the statue, which is characterized by its flexibility and non-reaction with the

Figure (7) the Nfrtum bronze statue **a.**, **b.** & **c.** after conservation processes, **d.** & **e.** after museum display in the *New Administrative Capital Museum*

6. Conclusion

The statue of Nefertum is considered one of the bronze statues that represents the ingenuity of the ancient Egyptian craftsman, his ability to shape and manufacture metal artifacts, his ability to use different colored glass pastes in the crown of the statue, and his skill in imitating precious stones through glass pastes. It became clear from the results of examinations and analyses that the statue was made of a bronze alloy. The effect of burying the statue in the soil and its discovery in excavations in the Saqqara archaeological area was revealed. Various corrosion compounds were formed on it, which were mixed with soil components, the most dangerous of which was the atacamite mineral, which represents chloride minerals and is one of the rust products that lead to the occurrence of bronze disease. The surfaces of the statue, as well as the glass pastes in the crown area, were affected due to the components of the soil. Various conservation processes were carried out for the statue, which included cleaning, insulation, and protection from exposure to rust, as well as its museum display in the New Administrative Capital Museum.

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