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ANCIENT EGYPTIAN METAL ARTIFACTS: LASTING FOR THOUSANDS OF YEARS AGAINST CORROSION

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Abstract

Metals were used to make artifacts and medical tools in ancient times. This review article focuses on the gold and silver metal artifacts of the ancient Egyptian and their protection against corrosion. There is no doubt that Egypt is an open museum because the ancient Egyptians planted the monuments everywhere in the deserts. There are many types of artifacts, such as statues, jewelries, furniture, weapons, paints, etc. They have used different types of materials to make all these monuments, such as marbles, wood, stones, metals. They have used different types of metals, such as gold, silver, iron, and copper. The museums in Egypt accommodate huge number of metals artifacts. Ancient Egyptian produced fine and gorgeous artifacts, especially rings, bracelets, and necklaces. The artifacts were created to be resistant to degradation and corrosion over a long period of time. They have used different ways of protection, such as paints, alloying, chemicals etc.

Keywords*:* *Ancient Egyptian, Gold artifacts, Silver artifacts, Corrosion, Artifacts protection*

Introduction

Metals were used to fabricate artifacts in the ancient Egyptian times. The main metals applied were gold, silver, iron and copper. Other elements, such as antimony, lead, zinc, and tin, were used in making artifacts of ancient Egyptian. The most abundant metals were gold and copper, and silver was relatively scarce. Regarding iron, it was in application during fourth millennium BCE, especially, meteoritic iron [1, 2]. Ancient Egyptians were very clever in making artifacts to reserve their history in temples, pyramids, tombs, tools, jewelries, papyrus, etc. Also, they have made various medical tools that were used in surgery and teeth treatments.

It is reported that from the point of view of historians and archaeologists, "Egypt's importance lies in the incredible detail in which the evidence of the past was preserved in the arid climate of ancient Egypt. What was destroyed elsewhere was, in Egypt, preserved or recorded in its art". Iron was a precious and important metal in ancient Egypt, but scientists and historians have long pondered the prehistoric civilization's understanding of metallurgy. That mystery has now been partially resolved: Meteorite-made artifacts are the earliest known examples of iron. The proof is in the shape of iron beads that date back to around 3300 B.C., more than 2,000 years before Egypt's Iron Age and before any commerce in iron items with other civilizations is known to have taken place [3]. Both the general public and academics are fascinated by ancient Egypt. The study of ancient Egyptian metallurgy is still in its early stages, and despite many of investigations of the chemical constitution and metal items technology of ancient Egyptian, there has yet to be a synthesis of what has been learned [4]. This review article discusses the resilience of gold and silver metal artifacts made by the ancient Egyptians for thousands of years, and the inhibition methods that the ancient Egyptians applied to resist corrosion and protect the gold and silver artifacts.

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Types of Artifacts

The ancient Egyptians created their artifacts from a variety of materials. They used stones, minerals, papyrus, and other types of materials. In fact, the metalwork is made to reflect the artistic spirit of each antique. Various types of metals are mostly used to make antiques and sculptures. The ancient Egyptian civilization fascinates all those interested in this civilization. The ancient Egyptians created wonderful works of art in stone, metal and wood. The artifacts have been made for more than 7,000 years and have retained their original appearance throughout history. All of the objects were created by designers using their full range of skills. Before the hand, artists draw with the heart. As seen in the Fig. 1, the artist, for instance, can create wonderful sculptures out of an uneven stone [5]. A Colossal Statue of Amenhotep III and Tiye made from stone and presented in Egyptian Museum Cairo [6].

Fig. 1. Statues Menkaure (Mycerinus) and Khamerernebty(?), graywacke, c. 2490-2472 B.C.E. [5]

Fig. 2. Tiye and Amenhotep III Statue, Egyptian Museum Cairo [6]

Various local stones were used for statues, including sandstone, calcite, and schist, as well as the typical soft limestone of the desert cliffs that surround most of the Nile valley. Granite, basalt, quartzite, and diorite are among the hardest stones. Brass chisels and stone tools were used to carve the softer stones; Tools made of hard stones, copper alloys, and abrasive sand were needed to shape the hard stones. The polishing process is completed using fine-grained abrasive sand and a fine-grained rub stone, as shown in Fig. 2 [5].

Additionally, they produced artwork in a variety of metals, such as gold, silver, bronze, and copper as well as copper alloys. Gold and silver, which according to myth served as the gods' skin and bones, were used to create the cult statues of the gods, which were frequently rather small.

The natural tamarisk, acacia, and cedar, fir, as well as sycamore figs, and other conifers brought from Syria were all utilised by Egyptian artists in their creations. The skill of artisans in putting together tiny, asymmetrical wood pieces and pinning them into position to make statues, furniture, boxes, and coffins was exceptional, as shown in Fig. 3 [5].

Fig. 3. Ceremonial gilded wooden shield from the tomb of Tutakhamun.
Egyptian Museum, Cairo (New Kingdom). Photo: Amy Calvert [5]

The excavation of ancient Egyptian antiquities began at the beginning of the twentieth century and perhaps at the end of the nineteenth century as well. As reported, Francis W. Kelsey from the University of Michigan, USA, had visited Egypt in 1920 and had started interesting and massive archaeological excavations. His journey of excavation started at Karanis village in Fayoum, south Cairo. Fayoum is about 1 hour driving from Cairo. Kelsey and his professional excavators started their excavations in November 1924 for eleven seasons [6]. Their discovers included five datable levels of debris at Karanis and three other areas in Fayoum. The three areas are the north temple, the south temple and the residential district. The work of Kelsey team was completed later by Faculty of Monuments, Cairo University, and by other international excavators, such as French Institute. According to documentation in Kelsey Museum in Michigan, they discovered more than 100,000 archaeological objects, and more than 2500 folders-worth of complete and partial documents were recovered from the excavation sites. Some coins in hoards have been discovered in Karanis. One of the most telling pieces of evidence to the scope of international trade and the power of Karanis as an agricultural centre during the late Roman and early Byzantine periods is provided by the most recent coins dating from the fourth century. The coins are fully covered with tarnish, which is surely accumulated on the coins through history. As stated, the Kelsey Museum in Michigan included all artifacts excavated in Karanis, which formed about 50% of the whole monuments in the museum, the 50% counted for 44,000 artifacts from Karanis, these huge numbers of monuments did not include the papyri in the papyrology room in the museum [6].

Applications of Technology

Ancient Egyptians had applied their own technology in some artifacts and medical tools. The Ancient Egyptians were rather conservative in the application of technological solutions. Even though they were aware of the socket eye as a more feasible technological option for tool and weapon blades, they continued to attach metal blades to tools with V-shaped wooden hafts and leather thongs. [1]. It is stated that “rom inventing our modern calendar, to inventing writing, to creating surgical instruments similar to those used today, the ancient Egyptians were truly masters of invention” [7]. Accordingly, “the ancient Egyptians would come to invent mathematics, geometry, surveying, metallurgy, astronomy, accounting, writing, paper, medicine, the ramp, the lever, the plow, and mills for grinding grain”. They invented alloys, such as bronze alloy, by mixing tin and copper. As shown in the following figure 4, the statues was made from bronze alloy. Bronze alloy was used to make various tools, such as building materials, decorative, weapons, and armor. It was called bronze age because of its application in many areas. The sickle blade was made from iron alloy to be used in cutting crops and grass, as shown in figure 5 [7]. The bronze alloy is highly resistance against corrosion, therefore, the statues in figure 4 has stayed without degradation up to today. Also, the sickle blasé was covered by oxide layers, which could protect it against corrosion and degradation. The Pharaohs built water wheels that powered their innovation, the shadoof. It was constructed of metal and wood and consisted of a long pole with a bucket at one end and a weight at the other [7]. This invention was used to irrigate lands. Also, they had invented water wheels to raise water from wells. These water wheels are still running up to toady in Fayum governorate and water is flooding in a canal.

Application of Chemistry in Protecting Artifacts

Ancient Egyptians were the pioneers in chemistry, even the name of chemistry, it is thought that it is derived from the expression “Kemet”, and it has a meaning the black land. Black land describes the colour of the nutrient-rich land deposited annually by the Nile. As mentioned, “the ancient Egyptians were the first civilization to synthesize an inorganic pigment – Egyptian blue”, also, it is stated that “It’s certainly true that the ancient Egyptians became skilled in what Marco Beretta, a historian at the University of Bologna in Italy, calls ‘the chemical arts’” [8]. It could be argued that they could apply pigments, such as Egyptian blue, to protect artifacts against degradation or corrosion. The best example to support this argument is the mummification. As we can see in the museums, there are plenty of mummies have been preserved for thousands of years without heavy degradation. This is because of the chemical compounds, which are used in the mummification process. In my view, there is no doubt that the ancient Egyptians have not randomly applied chemical compounds in their artifacts. It was discussed that they applied stoichiometry calculation to prepare Egyptian blue, and used oxidizing agent and a catalyst to do the preparation [8]. This is an amazing reaction process in which the researcher uses scientific procedures to make the reaction.

Gold Artifacts

One of the most significant components in the creation of ancient Egyptian artifacts is gold. Gold symbol is Au. It is originated from Latin word “aurum”. It has interesting properties, which make it a unique element. It has slightly orange-yellow color. It is soft, malleable, and ductile. It is easy to be reformed and to be workable. It has high density (19.3 g/cm^3 at room temperature). It has high melting (1064 ^{o}C) and high boiling points (2970 ^{o}C) [9].

Fig. 4. Ancient Egyptian bronze statues. Source: Andrew Bossi/Wikimedia Commons [7]

Fig. 5. Ancient sickle of iron alloy. Source: The Met/Wikimedia Commons [7]

One of the most important physical properties of gold is that it is soft and flexible, its resistance to corrosion, its resistance to most other chemical reactions, and its electrical conductivity. It has been used industrially in computers with corrosion-resistant electrical conductors. Infrared shielding, tinted glass manufacture, gold leafing, and tooth restoration all use gold. In medicine, certain gold salts are still employed as anti-inflammatories [9].

Gold is a mononuclidic and monoisotopic element since it only has one stable isotope, 197Au, and only one naturally occurring isotope. A total of 36 radioisotopes have been created, with atomic masses ranging from 169 to 205. 195Au has a half-life time of 186.1 days, and it is the most stable of gold isotopes. The least stable is 171Au is the least stable isotope, and it has a half-life of 30 s and decays by proton emission. With atomic masses below 197, the majority of gold's radioisotopes degrade through a mixture of emission of proton, beta decay, and gamma decay. The two exceptions are 195Au, which undergoes electron capture decay, and 196Au, which undergoes electron capture decay most frequently (93%) and undergoes a minor decay path 7% of the time [10, 11]. The presence of gold isotopes is considered an advantage because of their various applications, such as the treatment of cancer. In my view, Pharos used gold in various applications, such as jewellery and disease treatment.

Source of Gold

There are a number of metals have been used by Pharaohs since the pre-Dynastic period (prior to about 3100 BCE), these metals are gold, silver, lead and copper. The old rocks of Egypt's eastern desert near the Red Sea and in Sinai were the sources of the metals. Egypt is a land rich in gold, and the ancient Egyptian word for gold is “nbw” [9]. The main resources of gold in Egypt are Eastern Desert, and land of Nubia. Gold was discovered as mentioned by hieroglyphs in the First Dynasty, but gold artifacts were discovered during the earlier days of the fourth millennium BC.

Types of Gold Artifacts

Silver is frequently present in significant levels in the gold the ancient Egyptians used, and it appears that gold was not processed to boost purity over the majority of Egypt's history. A metal's composition determines its colour; for example, the Middle Kingdom uraeus pendant's paler greyish yellow hue and the bright yellow of a central boss that once decorated a vessel from the Third Intermediate Period can both be attributed to the naturally occurring presence of different amounts of silver.

As shown in the Figs. 5, 6 and 7, these are some gold jewelry artifacts used during ancient Egyptian. Gold was extracted from quartz veins, and the rocks were then ground.

Fig. 5. Child Bracelet of ancient Egypt [9]

Fig. 6. Ancient Egypt Model collar of Hapiankhtifi ca. 1981–1802 B.C. [9]

Tarnishing and Cleaning of Gold

Gold is a precious metal and it can stay thousands of years without decay, especially if the gold is pure. The ancient artifacts of gold prove this fact. Pure gold includes very few percentages of other metals, which can interact with oxygen or sulfur to tarnish. There are a number of materials can help to speed up tarnishing of alloys, such as human sweat, hairspray, lotion, perfume, and detergents. These products contain some elements that speed tarnishing of alloys. It is important to stop gold tarnishing. There are a number of measures can help to stop gold tarnishing. Gold must be kept dry because water, liquids and gases accelerate tarnishing of gold. It should be properly stored. Gold must be kept away from direct sunlight, which can tarnish it, in a dry container. For instance, you could put it in a velvet bag that blocks out light and moisture. The velvet bag can then be kept in a plastic container or an airtight Ziploc bag [12, 13]. Spray protection offers a barrier that prevents damaging substances from adhering to your gold surfaces. Nonetheless, be cautious when selecting a protective spray. While you wear your sprayed gold, some components can cause skin irritation, rashes, and other unfavourable side effects. Nanocoating is a method that can be used to protect gold against tarnishing in addition to the measures mentioned above. For instance, nanoalumina was used to protect silver alloy. Nanoalumina may be used to protect gold too [14].

Fig. 7. The gold mummy mask of King Amenemope, from the royal necropolis of Tanis discovered in 1939-1940 by Pierre Montet, the first intact Egyptian Pharaoh tomb ever discovered [9]

Cleaning of gold tarnish must be regularly done; this is to keep its brightness. The gold tarnish can be cleaned by using chemical solutions or using emery paper for polishing. Baking soda is a good solution for cleaning gold tarnish. The mild alkalinity of baking soda dissolve can remove dirt and grease. Ammonia and mild soap solution can remove gold tarnish. Also, dish soap and warm water can remove gold tarnish, but we must not use high concentration of dish soap to avoid damaging gold artifacts [13]. It is important to dry gold artifacts after cleaning. The artifacts should be stored in a dry container. Gold artifacts should be stored in a place protected against temperature variation and high humidity.

Silver Artifacts

History of Silver Artifacts

Silver has been used in beadmaking since the Predynastic Period (ca. 4400-3100 BC), and was popular in Egypt for personal adornment and sacred artefacts until Roman times, according to the History of Silverware. For most of Egypt's history, silver was valued more than gold, according to temple inscriptions. Unlike the gold mined in the Eastern Desert and Nubia, the sources of silver are unknown, and given the scarcity of local geological resources, much was almost certainly imported from neighboring countries [15]. As a result, because silver, especially hammered plates, is highly susceptible to the corrosive salts found in most Egyptian burial sites, silver appears in the Egyptian archaeological record less frequently than the metal gold or copper. Before the Early Middle Kingdom (ca. 2030-1650 BC), there were only a few known silver discoveries. A collection of semi-precious stone-encrusted bracelets and furniture fittings from the tomb of Hetepheres I, mother of the Fourth Dynasty pharaoh Khufu (r. ca. 2551-2528 BC), now shared between the Museum of Fine Arts, Boston and the Egyptian Museum, Cairo [15].

The oldest Egyptian silver in the Metropolitan Museum's collection comes from the women's tombs in the temple of the Eleventh Dynasty pharaoh Mentuhotep II (r. c. 2051-2000 BC) at Thebes, which was discovered by Herbert Wenlock in 1922-1923. Almost everything was in the form of small beads, but there was an unusual amulet of alternating electrum wires and silver wires held together by electrum bands (shown in Fig. 8) [15].

Fig. 8. Sa Amulet, ca. 2051–1981 B.C. [15]

The hieroglyph for the word "sa," which means "protection," is depicted on this amulet. The sa amulet provides protection to the wearer in both life and death. A "seweret" bead and a wooden box were also discovered in the same tomb.

Fig. 9. Amulet of Anubis on his Shrineca. 1850–1775 B.C. [15]

This beautiful amulet, as shown in Fig. 9, depicting a jackal lying atop a shrine, was discovered among numerous other silver artifacts in a tomb at Abydos. The jackal here is most likely Anubis, the god of embalming, or Wepwawet, the god who accompanied the deceased to the afterlife [15].

The earliest Egyptian silver in the Met's collection originates from women's tombs at the temple of Dynasty 11 pharaoh Mentuhotep II (r. ca. 2051–2000 B.C.) in Thebes, which Herbert Winlock unearthed in 1922–23. Almost everything is in the shape of little beads, but there was also an intriguing sa-amulet of alternating electrum and silver wires secured with electrum bands.

Manuwai was one of Thutmose III's three minor wives, all of whose names allude to their origins in western Asia. When these non-Egyptian ladies died, they were mummified and buried with the same accoutrements seen in a native Egyptian queen's tomb. Each was given a silver canister identical to this one, which resembles a libation vessel but lacks a spout, as shown in Fig. 10 [15].

Fig. 10. Libation Vessel of Manuwai, ca. 1479–1425 B.C. [15]

Ag alloyed with Cu-As properties are investigated and compared to those of pure Ag. The study refutes Eshel et al.'s (2021) contextual view that a sophisticated forgery by local administrators began during the Late Bronze Age III (1200-1150 BCE) is justifiable. The density discrepancies between the alloys and Ag yield a weight differential that is well within the sensitivity of balances used over a long time period, including the time the examined alloys were dated. In addition, the Weber fraction applied to weight and reflectance is used to quantify observable changes in weight and colour between the alloys and Ag. This investigation reveals significant variances in material properties exist for some of the alloys [16].

As shown in Fig. 11, the necklace of Wah has been discovered in the tomb of Wah. It was tied around the neck of Wah' mummies. As it is observed, the beads of silver look clean, which means that the beads were protected during embalming of the mummy. The excavator noticed that Wah's silver did not degrade, nor did the linen cords along which his necklaces were hung. This means that certain protection was added to the mummy whether as chemical materials or alloying elements added to the silver alloy. It was stated that “Silver was used to fashion beads as early as the Predynastic Period (ca. 4400–3100 B.C.) and remained important for personal ornaments and cult objects in Egypt through Roman times” [17].

In fact, silver sheet is susceptible to degradation and corrosion, especially if it buried for many years. As stated, “like gold, silver was hammered to produce leaf that was used to adorn various materials, but very little has survived”.

Fig. 11. The necklace of Wah with 11 clean beads of silver ca 1981-1975 BC [17]

Silver Tarnish Removal and Protection

Silver tarnish forms due to exposure to sulphur environment. The environment leads to silver tarnish, such as sulphur dioxide, hydrogen sulphide, sulphur dioxide, and organic sulphur compounds; liquid phases containing sulphide; and solid phases, such as elemental sulphur, egg, yolk, onions, wood, and so on, all have an effect on the tarnishing process. Tarnish products are formed on the surface of the artefacts during this procedure. These products on silver artefacts, such as Ag_2S, AgCl, and Ag_2SO_4, might be recognised [18].

Silver tarnishing mechanism in atmospheric environments is explained elsewhere [19-21]. In the liquid phase, the mechanism has been proposed as follows: a gradual induction process involving the slow production of silver oxide (Ag_2O) on the silver surface, followed by a reaction with hydrogen sulphide (H_2S)., as in equations 1 and 2.

$$Ag + \frac{1}{2}O_2 \rightarrow Ag_2O \quad (1)$$

Because silver has a very low affinity for oxygen, H_2S can operate in two ways: first, the oxygen in Ag2O can be replaced by sulphur to generate Ag_2S., as in equation 2.

$$Ag_2O + H_2S \rightarrow Ag_2S + H_2O \quad (2)$$

Second, as seen in equation 3, H_2S is able to interact with oxygen to generate sulphur, which then reacts with metallic silver, causing the film to develop at a rapid rate., as in equation 4.

$$H_2S + \frac{1}{2}O_2 \rightarrow H_2O + S \quad (3)$$

$$2Ag + S \rightarrow Ag_2S \quad (4)$$

Tarnish could be removed electrochemically, chemically, and mechanically. Electrochemical removal of silver tarnish, which was formed in presence of 0.1 M and 0,0001 M of Na_2S solution, was done by applying cathodic current density of 0.5 mA/cm^2 in 10 % (1:1) of sodium bicarbonate and sodium carbonates solution. This process gives a satisfactory tarnish removal [14]. Also, tarnish could be removed by galvanic coupling between aluminum alloy and silver tarnish in carbonate solution. Tarnish of silver can be mechanically removed by using fine emery papers and making mechanical polishing. This process needs to pay high attention to avoid damaging of artifacts. Silver artifacts could be protected after tarnish removal. Nanoalumina coating was applied to protect the artifacts surface [14, 19].

Conclusion

There is no doubt that ancient Egyptian civilization is great in its content and its effect on humanity. All over the world, we can see that Egyptology is one of the scientific fields in most of the prestigious universities and research institutes. The ancient Egyptians left precious, valuable, and priceless monuments and artifacts. They used various materials to fabricate their monuments and artifacts. They had used stones, wood, metals, papyrus, chemicals, dyes, fabrics, glass, and any other materials that could be handled to make things. As we could notice, they had fabricated artifacts from gold, silver and other metals. They had made alloys by mixing other metals with these metals to increase their resistance against degradation and corrosion. They applied chemicals compounds in the form of coatings and dyes to protect the artifacts against deterioration and degradation. Day after day, the civilization of ancient Egyptians continues to reveal its secrets and provide benefits to humanity in many aspects of life.

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