

Mechanical Engineering in Ancient Egypt, Part 103: Adhesives Industry

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Abstract:

This is the 103 paper in a series of research papers exploring the history of mechanical engineering during the Ancient Egyptian era. The paper investigates the industry of adhesives in Ancient Egypt over periods from Predynastic to Late Period. The paper presents inlays use in the ancient Egyptian art and investigates adhesive types used in securing the inlays. The work presents amulet inlay, pendants and pectorals inlay, bracelets and armllets inlay, finger rings inlay, mummy masks inlay and statues and coffins inlay. It presents also the use of adhesives in the cartonnage and papyrus industries.

Keywords — Mechanical engineering history, Ancient Egypt, adhesives industry, amulet inlay, pendants and pectorals inlay, bracelets and armllets inlay, finger rings inlay, mummy masks inlay, statues and coffins inlay.

I. INTRODUCTION

Adhesives is one of the supporting industries in ancient Egypt used to support jewellery, paper, wooden statues, coffins, mummification, boat building industries.

Lucas (1934) announced that the ancient Egyptian carpenters had reached a high degree of skill by the Old Kingdom. He gave example of wood works from the Old Kingdom, Middle Kingdom and New Kingdom and outlined the extensive use of mortise and tenon joints in some wooden products without evidence of glue. He analysed the eyes of the wooden statue of 'Sheikh el-Belad' and considered his statue as one of the highly skilled wood carving. He authorized the use of glue during the 18th Dynasty in many of the objects of Pharaoh Tutankhamun used to fasten wood together and to fix ebony and ivory inlay in place [1]. Kurtenacker (1973) outlined that the ancient Egyptians used adhesive substance of natural origins for producing their artefacts [2]. Scora and Scora (1991) outlined that the ancient Egyptians produced papyrus since the 1st Dynasty with the availability of 5200 years old one. They presented the opinions of other scientists about the type of adhesive used by them in producing the papyrus. This included: gum Arabic, egg white,

Acacia gum, glue, water soluble glucose and fructose [3].

Nicholson and Shaw (2000) in their book about ancient Egyptian material and technology presented a separate chapter about adhesives and binders written by R. Newman and M. Serico. The authors presented an analysis for a binding medium of a mummy portrait from Fayum and a filling material on the stone sarcophagus [4]. Petukhova (2000) presented a historical overview of fish glue as an artist's material used as binding media and adhesives. He stated that the fish glue adhesive was used in Egypt at least 3500 years ago [5]. Oldring (2003) outlined that coatings were used by the ancient Egyptians 5000 years ago. He stated that adhesives extracted from milk used in bonding wood were seen in many artefacts from the ancient Egyptian tombs [6].

Troalen, Guerra, Jim and Manley (2009) outlined that the common joining technique in ancient Egypt might have been through using 'hard soldering' using a copper salt and organic adhesive [7]. Bogdanov (2009) stated that in ancient tombs beeswax was used as an adhesive to join two surfaces together [8]. Rifai and El-Hadidi (2010) investigated three gilded wood samples from the tomb of Pharaoh Tutankhamun of the 18th Dynasty. Their analysis showed that the ancient Egyptians in the 18th Dynasty used linen textile glued using

animal glue to the wood base and the next gesso layer and a gesso layer and a binding medium between the textile layer and the gilding layer [9]. Abdel-Maksoud and El-Amin (2011) reviewed the materials used during the mummification process in ancient Egypt. They focused on some specific materials such as beeswax, gum Arabic and myrrh. They stated that the ancient Egyptians used gum Arabic as an adhesive when wrapping mummies [10].

FEICA (2016) outlined that the ancient Egyptians in 3500 BC developed an adhesive through boiling glue which was taken up by Greeks and Romans. They added that in 2000 BC, the ancient Egyptians used gelatin glue for furniture production and in 1500 BC they used glue in the production of furniture for King Tutankhamun [11]. Tenorio et. al. (2018) stated that a range of organic products for use as binding media were available in ancient Egypt including egg, animal glue, polysaccharide gums, plant resins, fats/oils and beeswax. They stated that glue-paint from the Old Kingdom tomb of Nefer at Saqqara where paint layers were identified as glue. They outlined also the use of glue mixed with oil in the production of a cartonnage during the 1st millennium BC [12].

Le Fay (2018) investigated the design and manufacturing techniques of the pectorals of Pharaoh Tutankhamun of the 18th Dynasty. He analyzed the bird pendants of the Pharaoh, the Udjat eyes necklaces, moon bark necklace, coronation necklace, Nekhbet necklace (all having inlays of various colors). He analyzed also the rebus pectoral, winged scarab pectoral, three designs of pendants, seven designs of pectorals. He stated that the inlays of the pectorals were between 1 and 2 mm of turquoise, lapis lazuli and carnelian, blue glass, obsidian, , feldspar and calcite. He concluded that inlays were applied by cements [13]. Patricio (2019) focused on three objects. The sold ebony chair of Pharaoh Tutankhamun and chairs of Queen Hetepheres. Analyzing the ebony chair he stated that four wood elements were used between chair legs with gilded bronze pieces. The back of the chair was inlaid with ivory [14]. Alhady, Azzam, Nageeb and Awadallah (2020) presented the pendant of Princess Sithathoriunet from the 12th Dynasty where it was made of gold inlaid with red

agate, lapis lazuli and turquoise. They presented also a pair of earrings for Pharaoh Tutankhamun made of gold, red agate, quartz, calcite, green and dark blue glass fixed with colored adhesive [15].

Abdelmoniem et. al. (2020) conducted an archaeometric study of a polychrome wooden coffin from the 26th Dynasty. They stated that the ancient Egyptians of the 26th Dynasty used an animal glue as an original binding medium in the ground layer of the coffin from early periods in ancient Egypt [16]. Sayed et. al. (2021) analysed a gilded cartonnage from the Late Period. They presented samples of the cartonnage under light microscope showing pieces of animal glue on the surface. They showed also a linen fibre with adhesive (animal glue) scattered within the layer [17]. Manfreda et. al. (2021) studied an Egyptian wood sculpture from the New Kingdom located in the Egyptian Museum of Turin. They concluded that gum Arabic was used as a binder [18]. Longejans et. al. (2022) defined an adhesive as any substance that bonds different materials together. They stated that in ancient Egypt, an animal glue formed part of a plaster named 'gesso' used as a ground layer for painted or gilded decorations on wood [19].

II. USE OF ADHESIVES IN ANCIENT EGYPT

The ancient Egyptians used adhesives in many applications throughout time periods starting from the first Dynasty. Here are some adhesive uses as recorded by various resources:

- They invented the process of veneering (gluing thin slices of wood together). The oldest example of this process was found in the tomb of Semerkhet (8th King of the 1st Dynasty (2930-2920 BC) [29] , [30]. Resin was used for this purpose in the beginning of the Old Kingdom and then glue was used later during the same period [30].
- During the 2nd Dynasty, (2890-2686 BC) they succeeded to fix two golden bored handles to a 100 mm height porphyry jar using an adhesive [32]. This fixture could sustain the environmental effects for more than about 4700 years.
- During the 6th Dynasty (2345-2181 BC), they succeeded to fix obsidian pupils to ivory

sclera for artificial eyes of a statue in display in the Louvre Museum at Paris using an adhesive [31].

- During the 12th Dynasty, they produced a wonderful pectoral for Princess Sithathoriunet, daughter of King Senusret II (1887-1878 BC). The pectoral had a 82x45 mm dimensions and was inlaid with 372 pieces produced using carnelian, lapis lazuli, turquoise and garnet [33] and [34].
- During the 17th Dynasty, they produced a distinct armband vulture bracelet for Queen Ahhotep (1560-1530 BC) mother of Pharaoh Ahmose I founder of the 18th Dynasty. The bracelet was produced from gold and inlaid with lapis lazuli, carnelian and turquoise [36].
- During the 18th Dynasty, they produced a hinged cuff bracelet for Thutmose III, 6th Pharaoh of the 18th Dynasty (1479-1425 BC) in display in the Metropolitan Museum of Art. It was produced from solid gold inlaid with carnelian and turquoise [35].
- During the 22nd Dynasty, they produced Royal bracelets for Shoshenq II, the 3rd Pharaoh of the 22nd Dynasty (887-885 BC) produced from gold and inlaid with lapis lazuli, carnelian and white faience [37].

III. AMULETS INLAY

The ancient Egyptians used amulets with various designs and materials. Because they loved beauty in all their life aspects, they inlaid their amulets to give them better appearance and sustained colors. Here are some examples:

- **Example 1:** Fig.1 shows an ivory 49 mm height elephant head amulet from Naqada II/Naqada III Periods of ancient Egypt (3500-3100 BC) in display in the Brooklyn Museum, New York [38]. It has the inlay features:
 - It may be the first example of a complete eye inlay.
 - The inlay of each eye is composed of two stones.
 - The pupil and eye lashing may be a basalt inlay since basalt was known in ancient Egypt from about 4000 BC.

- The iris may be an amazonite since it was known in ancient Egypt since the end of Naqada III.
- The two inlay materials may be secured in position using natural tree-glue since it was known from a very early time (about 200,000 years [39]).

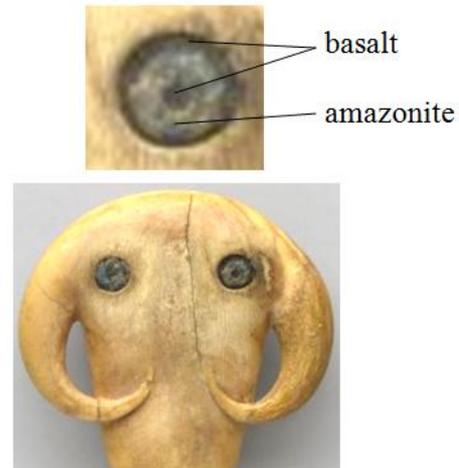


Fig.1 Elephant's head amulet from Naqada II/Naqada III Periods [38].

- **Example 2:** Fig.2 shown a 28 mm golden fish amulet from the Middle Kingdom (2055-1650 BC) in display in the British Museum [40]. The amulet was inlaid by green feldspar. It has the inlay features:
 - The inlay of each side of the fish is composed of one stone (green feldspar).
 - Most properly the inlay was secured in position using an animal glue which found application during the Middle Kingdom [39].



Fig.2 Fish amulet from the Middle Kingdom [40].

- **Example 3:** Fig.3 shown a 35 mm length turtle amulet from the 12th Dynasty of the Middle Kingdom (1991-1802 BC) in display in the Metropolitan Museum of Art, New York [41]. The amulet was produced using amethyst and inlaid by turquoise, lapis lazuli and carnelian. It has the inlay features:
 - The inlay of the turtle back is composed of several circular inlays of various colours depending on the semi-precious stone used as depicted in Fig.3. Some of the inlays are not identified.
 - One of the undefined inlay is the black inlay which I suggest that it is obsidian since it was known and imported since the Naqada I Period (4000-3500 BC) [42].
 - The second inlay is a light green semiprecious stone which I guess it is turquoise which was known in ancient Egypt since the time of Naqada III (3000 BC) [43].
 - The third inlay is a blue semiprecious stone which I guess it is lapis lazuli which was known in ancient Egypt since the time of Naqada I (4000-3500 BC) [44].
 - Most properly, all the inlays were secured in position using the animal glue which was known during the Middle Kingdom [39].

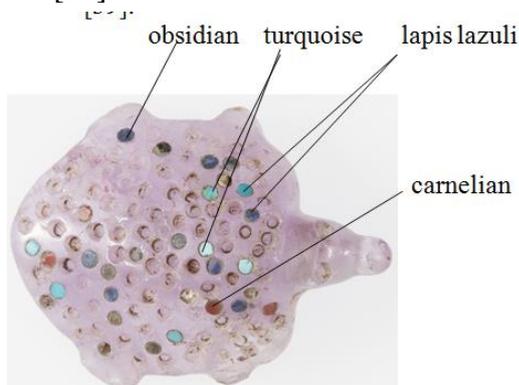


Fig.3 Turtle amulet from the 12th Dynasty [41].

- **Example 4:** Fig.4 shows a steatite heart-amulet of Royal Scribe Ay during the reign of Akhenaten, the 10th Pharaoh of the 18th dynasty (1351-1334 BC) in display in the

British Museum, London [43]. The amulet was inlaid by a scene showing Ay adoring a benu-bird. The amulet was produced using steatite and inlaid by quartz and calcite as I expect. It has the inlay features:

- The first inlay on the amulet is for the Scribe Ay adoring a bird. It is composed of two different stones one for his dress and the second for his hands and legs. I guess that his dress was cut from quartz while his hands and legs were cut from calcite.
- The second inlay is for the benu-bird which was cut from one stone which I guess that it was calcite.
- The inlays may be secured in position using an animal glue introduced during the Middle Kingdom [39] or a new adhesive material introduced in Early 18th Dynasty which is a lime plaster [45].



Fig.4 Heart amulet of Scribe Ay from the 18th Dynasty [43].

IV. PENDANTS AND PECTORALS INLAY

The ancient Egyptians used pendants and pectorals as an important elements in the adornment systems in ancient Egypt. They designed and produced different designs using various materials and inlaid some of them using semiprecious stones. Here are some examples:

- **Example 1:** Fig.5 shows a golden Nile catfish pendant from the 12th Dynasty (1985-1773 BC) in display in the Walters Art Museum, Baltimore [46]. The pendant was inlaid by a number of stones. It has the inlay features:

- The inlay of the catfish is composed of several irregular slices secured in position from both sides of the fish.
- The first and third slices had grey colour which I identified as serpentine which was known in ancient Egypt since the time of Naqada II (3650-3550 BC) [47]. Another alternative for those slices is grey amethyst known in ancient Egypt since Naqada III (3200-3000 BC) [48].
- The second slice had a purple colour which I identified as an amethyst which was known in ancient Egypt since the time of Naqada III (3200-3000 BC) [48].
- The fourth and fifth slices are missing.
- The right eye of the fish was inlaid with a red stone identified as garnet since it was known in ancient Egypt since the time of Naqada I (4000-3500 BC) [49].
- The left eye of the fish was inlaid with a green stone identified as turquoise since it was mined in ancient Egypt since 6000 BC [50].
- Most probably the inlays were secured in position using an animal glue which was used during the 11th Dynasty to produce papyrus rolls and furniture [51].

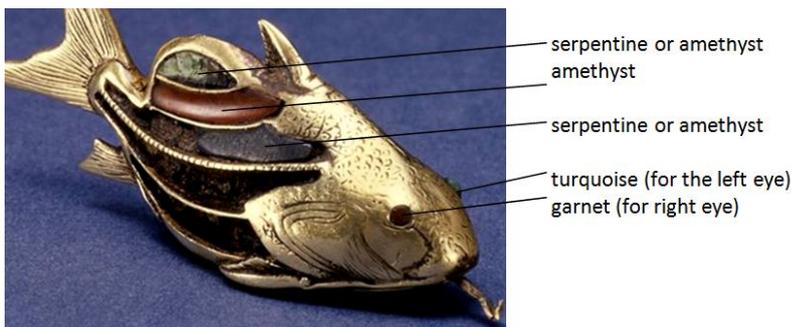


Fig.5 Catfish pendant from the 12th Dynasty [46].

- **Example 2:** Fig.6 shows a golden pendant for Princess Sithathoriunet, daughter of Senusret II (the 4th King of the 12th Dynasty (1897-1879 BC) in display in the Metropolitan Museum of Art , New York [52]. To identify the inlays used a part of the pendant is zoomed and presented in Fig.7. The pendant was inlaid by a number of semiprecious stones. It has the inlay features:

- The inlay of the Princess pendant is composed of very large number of small and medium inlays of different colours.



Fig.6 Sithathor pendant from the 12th Dynasty [52].



Fig.7 Inlay identification of Sithathoriunet pendant.

- The scarab inside the cartouche has a black colour and thus I identify it as an obsidian stone known in ancient Egypt since the time of Naqada I (4000-3500 BC) [42].
- The circular objects on the head of Horus (dark green), Horus feather on wings and right leg and sitting object top dress (light green) are identified as turquoise known in ancient Egypt

since the time of Naqada III (3000 BC) [53].

- The sun model inside the cartouche of the king and in the 'shin symbol' in the right talons of Horus have an orange colour which I identify as carnelian stone which was known in ancient Egypt since the Predynastic Periods (3500-3100 BC) [54].
- The Uraeus symbol head, chest and tail and Horus wing and left leg feathers have a blue colour which I identify as lapis lazuli stone which was known in ancient Egypt since the time of Naqada I (4000-3500 BC) [44].
- The Horus wings were inlaid using two semiprecious stones (lapis lazuli and turquoise) arranged in two alternated rows.
- Most probably the inlays were secured in position using an animal glue which was known in ancient Egypt since the Neolithic Period (6000 BC) [55].

- **Example 3:** Fig.8 shows an electrum winged scarab pendant from the 12th Dynasty (1890 BC) in display in the British Museum [56]. The pendant was inlaid by a number of semiprecious stones. It has the inlay features:

- The inlay of the winged scarab pendant is composed of a limited number of medium inlays of three colours.



Fig.8 Scarab pendant from the 12th Dynasty [55].

- The scarab inlay of the winged scarab consists of four pieces isolated by golden strips. The four pieces inlays are blue and produced from lapis lazuli.

- The wings of the scarab are inlaid using three semiprecious stones: lapis lazuli, feldspar and carnelian. Two inlays from each colour (blue, green and orange).
- The two lotus flower elements in the bottom of the pendant are inlaid by green feldspar.
- The base where the scarab is standing us are inlaid by lapis lazuli and carnelian.
- Most probably the inlays were secured in position using an animal glue which was known in ancient Egypt since the Neolithic Period (6000 BC) [55].

- **Example 4:** Fig.9 shows a golden winged scarab pendant of Tutankhamun, 13th Pharaoh of the 18th Dynasty (1332-1323 BC) in display in the Egyptian Museum [57]. The pendant was inlaid by a number of semiprecious stones. A pendant half is considered in Fig.10 for inlay identification. It has the inlay features:

- The scarab body had a dark blue colour and is expected to be lapis lazuli known in Egypt 6000 years ago [44].



Fig.9 Scarab pectoral from the 18th Dynasty [57].

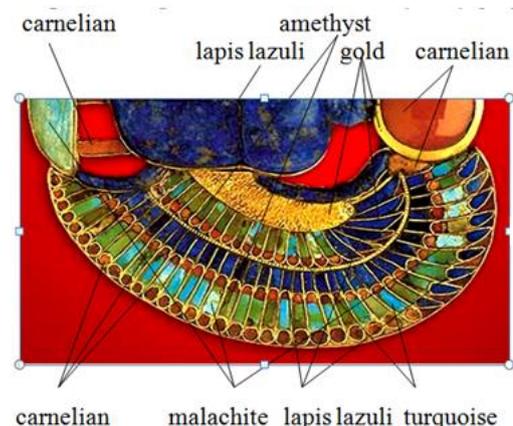


Fig.10 Inlay identification for the Scarab pectoral from the 18th Dynasty.

- The scarab wing was designed using three main adjacent layers inlaid with different semiprecious stones and bounded by a curved array of circular adjacent elements.
- I think the first layer was inlaid by amethyst (brown), turquoise (bright green) and lapis lazuli (dark blue). The brown amethyst was used in the jewellery industry in ancient Egypt since the First Intermediate Period (2181-2055 BC) [58]. The turquoise was known in ancient Egypt since the time of Naqada III [43]. The lapis lazuli was known in Egypt since the time of Naqada I [44].
- The second layer was inlaid only by lapis lazuli.
- I think the third layer was inlaid by malachite (light green) known in Egypt since the time of Naqada I (4000 BC) [59], turquoise (dark green) and amethyst (light brown).
- The sun disc above the head of the scarab had an orange colour and was produced from carnelian known in ancient Egypt more than 5100 years ago [54].
- The outside boundaries of the three wing-layers were composed of adjacent small carnelian discs with golden enclosures.
- We are with an ornament from the age of the 18th Dynasty belonging to Pharaoh Tutankhamun.
- The ancient Egyptians succeeded to use adhesives to secure the inlays used in this pectoral in position for more than 3300 years.
- Most probably, the adhesive used was animal glue known in ancient Egypt since 6000 BC [55]. Another alternative is using lime plaster invented during the 18th Dynasty [60].

- **Example 5:** Fig.11 shows a golden Udjat eye pectoral of Tutankhamun, 13th Pharaoh of the 18th Dynasty (1332-1323 BC) in display in the Egyptian Museum [61]. The pectoral was inlaid by a number of semiprecious stones. It has the inlay features:

- This application is on large inlays compared with small inlays in Fig.3, Fig.6 and Fig.9 and medium inlays in Fig.5 and Fig.8.

lapis lazuli calcite feldspar



obsidian carnelian lapis lazuli

Fig.11 Udjat eye pectoral from the 18th Dynasty [61].

- The eyebrow, eyelashes and the vertical and helical elements of the Udjat eye are all made of the lapis lazuli known in ancient Egypt since the time of Naqada I [44]. Moreover, the head and chest of the Uraeus symbol and the wings feathers and tail of the Nekhbet symbol are all produced using lapis lazuli.
- The bottom part of the Uraeus symbol is inlaid by carnelian known in Egypt since 5500 years ago [54].
- I think the eye while was inlaid using white calcite which was known and used to produce artefacts since the Early Dynastic Period (2920-2649 BC) [62].
- I think the space between the eyebrow and eyelashes was inlaid by feldspar which was known in ancient Egypt since the time of the 12th Dynasty (1991-1797 BC) [63].

- Most probably, the adhesive used to secure all the inlays in position was animal glue known in ancient Egypt since 6000 BC [55]. Another alternative is using lime plaster invented during the 18th Dynasty [60].

V. BRACELETS AND ARMLETS INLAY

The ancient Egyptians used bracelets and armlets an important elements in the adornment systems for men and women lived in ancient Egypt. They designed and produced different designs using various materials and inlaid some of them using semiprecious stones. Here are some examples:

- **Example 1:** Fig.12 shows a silver bracelet for Queen Hetepheres from the 4th Dynasty (2600 BC) in display in the Egyptian Museum, Cairo [64]. The bracelet was inlaid by a number of stones. It has the inlay features:
 - The inlay of the bracelet is composed of a butterfly separated by a number of sun-disks. The inlays can be classified as those having small sizes with four different colours.



turquoise lapis lazuli calcite carnelian

Fig.12 Bracelet from the 4th Dynasty [64].

- Some parts of the butterfly wings are made of the turquoise known in ancient Egypt since the time of Naqada III [43].
- The dark blue inlays in the butterfly wings are made of lapis lazuli known in ancient Egypt since the time of Naqada I [44].

- I think the that the white inlays in the butterfly wings are made of calcite which was known and used to produce artefacts since the Early Dynastic Period [62].
- The sun-disk in both sides of the butterfly was produced from carnelian known in Egypt during the Predynastic Periods [54].
- Most properly, all the inlays were secured in position using the animal glue which was known during the Neolithic Period (6000 BC) [55].

- **Example 2:** Fig.13 shows a golden armlet for Queen Ahhotep from the 17th Dynasty (1560-1530 BC) in display in the Egyptian Museum, Cairo [65]. The bracelet was simulating a vulture and intensively inlaid by a number of semiprecious stones. It has the inlay features:

- The whole external surface is inlaid with small to medium inlay pieces simulating the vulture wings, legs and tail.



Fig.13 Armlet from the 17th Dynasty [65].

- For purpose of inlay identification, a section of the armlet is presented in Fig.14 while rotated 180 degrees.
- The head of the vulture is produced from lapis lazuli known in ancient Egypt since the time of Naqada I [44].
- The beak of the vulture had a black colour and I think it was inlaid using obsidian which was known in ancient Egypt since the time of Naqada I [42].

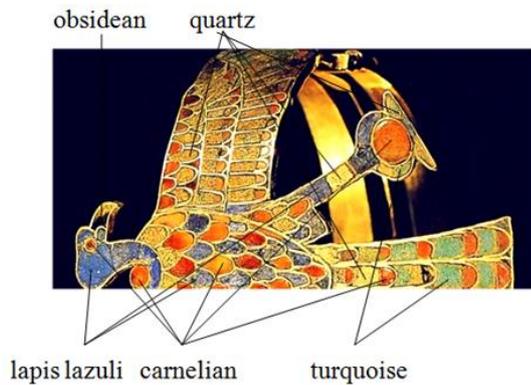


Fig.14 Inlay identification for the vulture armlet from the 17th Dynasty.

- The three boats under Uraeus are produced from green turquoise.
- The Uraeus were produced from lapis lazuli and carnelian. The sun disks were produced from carnelian bounded by circular sleeve produced from quartz (probably).



Fig.15 Flexible bracelet from the 18th Dynasty [67].

- I think that the wings were inlaid by lapis lazuli, carnelian (known in ancient Egypt since the time of Naqada II/Naqada III) [54] and quartz (used in Egypt for jewellery production since the time of the First Intermediate Period [66]).
- The tail was inlaid by lapis lazuli, carnelian, quartz and turquoise (known in ancient Egypt since the time of Naqada III [43]).
- The claw of the vulture was inlaid by lapis lazuli and holding a shen with sun disk produced from carnelian and a base produced from quartz (probably).
- Most properly, all the inlays were secured in position using the animal glue which was known during the Neolithic Period (6000 BC) [55] or a pinus genus resin found application in jewellery production during the 17th Dynasty [66].

- The parts of the scarab divisions were separated by thin strips of carnelian. The legs of the scarab were bounded by strips of carnelian.
- Securing the bracelet elements on the flexible base is not clear. One of the alternatives of this process is to use an adhesive. The adhesive used may be an animal glue (known since the Neolithic Period [55]), Pinus, genus resin (known since Dynasty 17 [66] or lime plaster (known since early 18th Dynasty [60]).

- **Example 3:** Fig.15 shows a golden flexible cuff bracelet for Tutankhamun, 13th Pharaoh of the 18th Dynasty (1332-1323 BC) in display in the Metropolitan Museum of Art, New York (!) [67]

- The bracelet was identified by three large scarabs separated by Uraeus symbol on a boat and carrying a sun-disk. It has the inlay features:

- The body of the bracelet is flexible consisting of strands of two-colours beads adjacent to each other.

- **Example 4:** Fig.16 shows a golden solid bracelet for Psusennes I, 3rd Pharaoh of the 21st Dynasty (1047-1001 BC) in display in the Egyptian Museum, Cairo [68].

- The Royal bracelet was identified by one scarab located exactly in the centre and bounded by an ankh and Uraeus symbols from both sides on a boat on a base representing the River Nile. The scarab is shown carrying a sun-disk inside a circular sleeve. It has the inlay features:

- The body of the bracelet was produced from solid gold supporting various inlays.

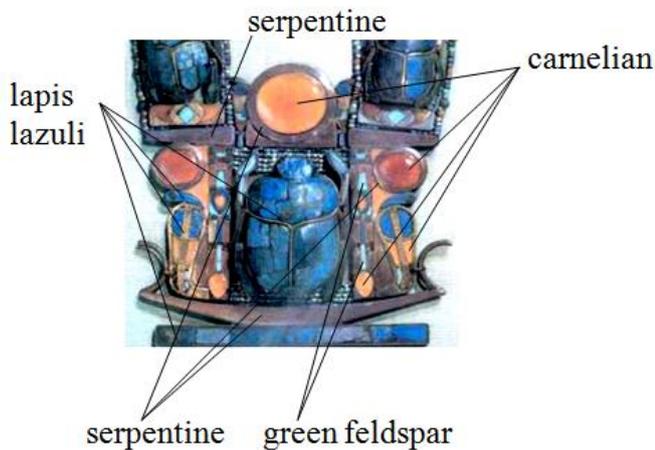


Fig.16 Bracelet from the 21st Dynasty [68].

- The scarab, Uraeus head and part of chest, part of ankh symbol and the base under the boat were all inlays produced from lapis lazuli known in Egypt since Naqada I [44].
- The sun disks carried by the scarab and the two Uraeus, part of Uraeus chest and the sun disks under the ankh symbol were produced from carnelian known in Egypt since Naqada II/III Periods [54].
- The ankh symbol parts were inlaid by lapis lazuli and green feldspar known in ancient Egypt since the 12th Dynasty [43].
- The circular sleeves around the sun disk carried by the scarab and Uraeus and the boat were all probably produced from serpentine known in ancient Egypt since Naqada II [69].
- The straight sleeve above the symbols (depending on its colour) may be produced from serpentine).
- Securing the bracelet elements on the golden background base may be performed using an animal glue (known since the Neolithic Period [55]), Pinus, genus resin (known since the 17th Dynasty [66]

or lime plaster (known since early 18th Dynasty [60]).

- **Example 5:** Fig.17 shows a golden solid bracelet for Shoshenq II, 3th Pharaoh of the 22nd Dynasty (887-885 BC) in display in the Egyptian Museum, Cairo [70].

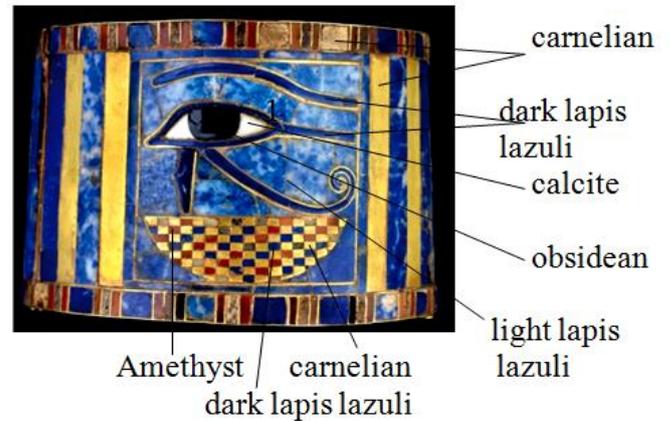


Fig.17 Bracelet from the 22nd Dynasty [70].

- The Royal bracelet was identified by a wadjet eye located exactly in the centre and bounded by two vertical sleeves from both sides. The eye is shown located on a decorated boat. It has the inlay features:
 - The body of the bracelet was produced from solid gold supporting various inlays.
 - The eyebrow, eyelashes and the supports under the eye were all inlays produced from dark lapis lazuli known in Egypt since Naqada I [44] and bounded by thin carnelian known in ancient Egypt since Naqada II/III Periods [54].
 - The eye white inlay was probably produced from calcite used in ancient Egypt for artefacts production since the Early Dynastic Period [62].
 - The eye pupil was inlaid probably by obsidian known in ancient Egypt since the Naqada I Period [71].
 - The background of the wadjet eye was produced from probably a light

lapis lazuli which is one of the lapis lazuli stone colours [72].

- The decoration from all sides of the bracelet was designed to take various shapes of orange colour achieved using carnelian inlays.
- The boat under the Wadjet eye symbol was inlaid alternatively using small carnelian dark lapis lazuli and amethyst known in ancient Egypt during the time of Naqada III [48].
- Securing the bracelet inlays on the golden background base may be performed using an animal glue (known since the Neolithic Period [55]), Pinus, genus resin (known since the 17th Dynasty [66] or lime plaster (known since early 18th Dynasty [60]).

VI. FINGER RINGS INLAY

The ancient Egyptians designed and produced finger rings for the adornment of both men and women lived in ancient Egypt. They inlaid some of them using semiprecious stones. Here are some examples:

- **Example 1:** Fig.18 shows a golden finger ring for Princess Sithathuryunet from the 12th Dynasty (1887-1813 BC) in display in the Metropolitan Museum of Art, New York [73]. The Princess finger ring was inlaid by a number of stones. It has the inlay features:
 - The inlay of the finger ring bezel is composed of a parallel slices on the back of the scarab, lateral thick sleeve between its head and back and half-circular element representing its head. The inlays can be classified as those having medium and large sizes with four different colours. All the inlays were isolated by golden thin slices (probably).



amethyst carnelian turquoise lapis lazuli
Fig.18 Finger ring from the 12th Dynasty [73].

- The head of the scarab bezel was produced probably from grey amethyst known in ancient Egypt since Naqada III [48].
 - The thick sleeve next to the scarab head is produced from carnelian known in ancient Egypt since the Predynastic Periods [54].
 - The seven longitudinal slices inlays on the back of the scarab were produced from lapis lazuli known in ancient Egypt since Naqada I [44] and turquoise known in ancient Egypt since [43]. They were arranged longitudinally four slices lapis lazuli and three slices turquoise.
 - All the inlays were isolated by golden thin slices.
 - Securing the finger ring inlays on the golden background base may be performed using an animal glue (known since the Neolithic Period [55]).
- **Example 2:** Fig.19 shows a golden finger ring from the New Kingdom Dynasty (1550-1077 BC) displayed by Live Auctioneers on 24 May 2016 for sale with price from 12,177 to 17,048 US \$ [74]. The finger ring was inlaid by a number of stones and has the inlay features:
 - The circular discs at the two vertices of the elliptical bezel was produced probably from beige quartz used in statues production since the 1st Dynasty [75].



quartz lapis lazuli carnelian malachite

Fig.19 Finger ring from the New Kingdom [74].

- The blue pentagon, triangle and semi-rectangle inlays were produced from lapis lazuli known in ancient Egypt since Naqada I [44].
- The brown kite inlays were produced from carnelian known in ancient Egypt since the Predynastic Periods [54].
- The light green triangle inlays were probably produced from malachite known in ancient Egypt since Naqada I [76].
- All the inlays were isolated by probably golden thin slices.
- Securing the bracelet inlays on the golden background base may be performed using an animal glue (known since the Neolithic Period [55]), Pinus, genus resin (known since the 17th Dynasty [66] or lime plaster (known since early 18th Dynasty [60]).

VII. MUMMY-MASKS INLAY

The ancient Egyptians designed and produced masks as funerary elements for both elite men and women lived in ancient Egypt. They inlaid some of them using semiprecious stones. Here are some examples:

- **Example 1:** Fig.20 shows a gilded cartonnage mummy-mask for Yuya, Courtier during the reign of Thutmose IV, 8th Pharaoh of the 18th Dynasty (1398-1388 BC) in display in

the Egyptian Museum, Cairo [77]. The Mask was inlaid by a number of stones and has the inlay features:

lapis lazuli obsidian calcite



Fig.20 Mummy-mask of Yuya from the 18th Dynasty [77].

- The inlays of the eyebrows and eyelashes of the mask were produced probably from polished lapis lazuli known in ancient Egypt since Naqada I [44].
- The inlays of the each eye-pupil was produced from obsidian known in ancient Egypt since Naqada I [71].
- The eye-white inlay was probably produced from calcite used in ancient Egypt for artefacts production since the Early Dynastic Period [62].
- Securing the bracelet inlays on the golden background base may be performed using an animal glue (known since the Neolithic Period [55]), Pinus, genus resin (known since the 17th Dynasty [66] or lime plaster (known since early 18th Dynasty [60]).

- **Example 2:** Fig.21 shows a gilded cartonnage mummy-mask for Tjuya, wife of Courtier Yuya, Mother of Queen Tiye and Grandmother of Pharaoh Akhenaten. Lived during the reign of Amenhotep III, 9th Pharaoh of the 18th Dynasty (1388-1350 BC) in display in the Egyptian Museum, Cairo

[78]. The Mask was inlaid by a number of stones and has the inlay features:



Fig.21 Mummy-mask of Tjuya from the 18th Dynasty [78].

- The features of the inlays of the mummy-mask of Tjuya are similar to that of Courtier Yuya presented in Example 1.

- **Example 3:** Fig.22 shows a golden mummy-mask for Tutankhamun, 13th Pharaoh of the 18th Dynasty (1332-1323 BC) in display in the Egyptian Museum, Cairo [79]. The Mask was inlaid by a number of stones and has the inlay features:



Fig.22 Mummy-mask of Tutankhamun from the 18th Dynasty [79].

- The inlays of the Uraeus symbol on the Nemes crown of the mask are probably obsidian known in ancient Egypt since Naqada I [71], carnelian known in ancient Egypt since the Predynastic Periods [54] and turquoise known in ancient Egypt since Naqada III [43].
- The inlays of the eyebrows and eyelashes of the mask were produced probably from polished lapis lazuli known in ancient Egypt since Naqada I [44].
- The inlays of the each eye-pupil was produced from obsidian known in ancient Egypt since Naqada I [71].
- The eye-white inlay was probably produced from calcite used in ancient Egypt for artefacts production since the Early Dynastic Period [62].
- Securing the bracelet inlays on the golden background base may be performed using an animal glue (known since the Neolithic Period [55]), Pinus, genus resin (known since the 17th Dynasty [66] or lime plaster (known since early 18th Dynasty [60]).

VIII. STATUES AND COFFINS EYES

The ancient Egyptians designed and produced statues and coffins for highly official staff using wood, bone, metallic and stone materials. They inlaid some of them using semiprecious stones. Here are some examples:

- **Example 1:** Fig.23 shows a bone figurine from Naqada I (4000-3600 BC) in display in the British Museum, London [80]. The figurine was inlaid by two stones and has the inlay features:

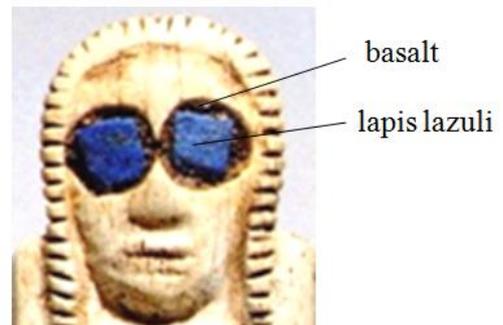


Fig.23 Bone figurine from Naqada I [80].

- The ancient Egyptians could carve bones without any mechanical destroy of the bone as a raw material more than 5600 years ago.
- They carved a circular groove for the eye and filled it with probably a basalt inlay known in ancient Egypt since Naqada I period [81].
- I think that the square blue inlay represents glasses made of lapis lazuli known in ancient Egypt since Naqada I [44]. The reason for this is that the ancient Egyptians knew well the anatomy of the human eyes as was clear in the statues of the Old Kingdom [82].
- Securing the eyes inlays on the bone base may be performed using an animal glue (known since the Neolithic Period [55]).

- **Example 2:** Fig.24 shows a plastered and painted wooden statue of Ka-aper, Mayor of the People from the 5th Dynasty (2400 BC) in display in the Egyptian Museum, Cairo [83]. The statue eyes were inlaid by three stones and have the inlay features:

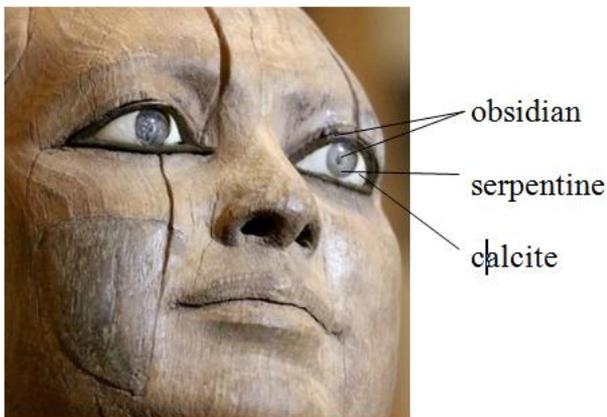


Fig.24 Wooden statue from the 5th Dynasty [83].

- The inlays of the eyelashes and eye-pupil was probably produced from obsidian known in ancient Egypt since Naqada I [71].
- The eye-white inlay was from calcite used in ancient Egypt for artefacts production since the Early Dynastic Period [62].

- The eye iris was probably produced from grey-serpentine known in ancient Egypt since Naqada II [69].
- Securing the eye inlays on the wooden background base may be performed using an animal glue (known since the Neolithic Period [55]).

Example 3: Fig.25 shows a the inner coffin of Sepi III, General of the 15th Nome of Upper Egypt during the 12th Dynasty (1991-1802 BC) in display in the Egyptian Museum Cairo [84]. The coffin eyes were inlaid by four stones and have the inlay features:

- The inlays of the eyebrows was probably produced from lapis lazuli known in ancient Egypt since Naqada I [44].
- The inlays of the eyelashes and eye-pupil was probably produced from obsidian known in ancient Egypt since Naqada I [71].
- The eye-white inlay was probably produced from calcite used in ancient Egypt for artefacts production since the Early Dynastic Period [62].
- The eye iris was probably produced from amethyst known in ancient Egypt since Naqada III [48].
- Securing the eye inlays on the wooden background base may be performed using an animal glue (known since the Neolithic Period [55]).

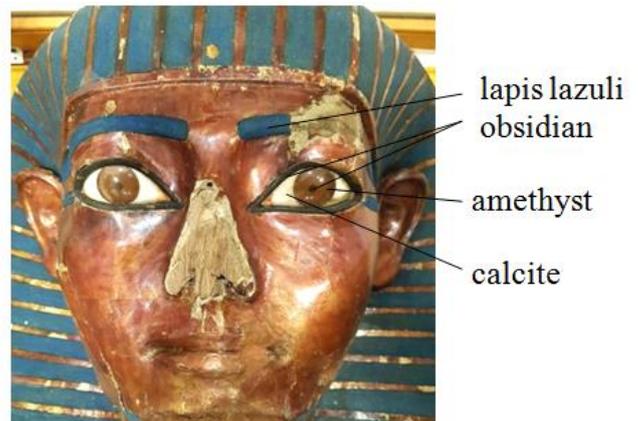


Fig.25 Inner coffin of Sepi III, from the 12th Dynasty [84].

Example 4: Fig.26 shows a coffin eye from the 12th Dynasty (1980 BC) in display in the Cleveland Museum of Art, Ohio [85]. The eye was inlaid by two stones and have the inlay features:



Fig.26 Coffin eye from the 12th Dynasty [85].

- The inlay of the eye-pupil was produced from obsidian known in ancient Egypt since Naqada I [71].
- The eye-white inlay was produced from a creamy alabaster known in ancient Egypt since the Predynastic Periods (I to III) [86].
- Securing the eye inlays on the wooden background base may be performed using an animal glue (known since the Neolithic Period [55]).

IX. CARTONNAGE PRODUCTION

The ancient Egyptians invented cartonnage as an artificial composite raw material used to manufacture funerary masks since the First Intermediate to the Roman Periods [87] and the inner coffin of elite people since the Third Intermediate to the Late Periods [88]. Here are some examples:

- **Example 1:** Fig.27 shows a cartonnage segment Third Intermediate to Late periods (1070-332 BC) was in display in by Skull Store, Canada for sale for 2981 US \$ [89]. It has the features:

- It was decorated by coloured drawings and a scene for papyrus flower and bud in the centre of the hemi-circle segment.
- The top part of the segment was decorated by funerary scenes and texts.
- The cartonnage segment is probably produced from linen coated by plaster used starting from the First Intermediate Period

to produce cartonnage for mask production [87].



Fig.27 Cartonnage segment from Third Intermediate to Late periods [89].

- **Example 2:** Fig.28 shows a painted cartonnage coffin from the Third Intermediate period (850-750 BC) in display in the Walters Art Museum, Baltimore [90]. It has the features:

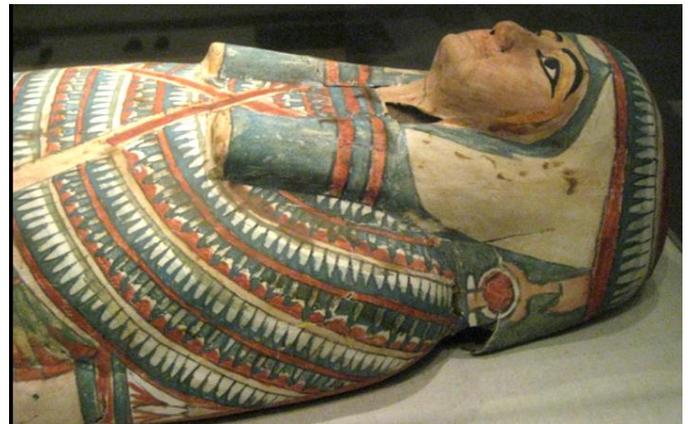


Fig.28 Cartonnage coffin from Third Intermediate Period [90].

- The coffin was decorated by coloured drawings covering the whole external surface.
- The diseased woman was shown wearing a head dress not a wig as a most of the Egyptologists say [91], [92].

- The cartonnage segment is probably produced from linen coated by plaster used starting from the First Intermediate Period to produce cartonnage for mask production [87].

- **Example 3:** Fig.29 shows a cartonnage panel from the 23rd Dynasty (837-728 BC) in display in the California Institute of World Archaeology, California [93]. It has the features:



Fig.29 Cartonnage panel from 23rd Dynasty [93].

- The panel was inscribed by a hieroglyphic text and a scene for Horus Deity holding a feather.
- The cartonnage panel is probably produced from linen (or papyrus) coated by plaster used starting from the First Intermediate Period to produce cartonnage for mask production [87].

- **Example 4:** Fig.30 shows a cartonnage panel from the Late Period (664-332 BC) in display through a Private Collection, New York [94]. It has the features:



Fig.30 Cartonnage panel from Late Period [94].

- The panel was extensively decorated by coloured scenes for a winged scarab and a seated winged deity. Both were boarded by floral scenes and two other deities from both sides. The design and painting is more than wonderful reflecting the high quality of the ancient Egyptian art.
- The cartonnage panel is probably produced from linen (or papyrus) coated by plaster used starting from the First Intermediate Period to produce cartonnage for mask production [87].

- **Example 5:** Fig.31 shows a cartonnage coffin of Nesmutaatneru from the 25th Dynasty (760-660 BC) in display in the Museum of Fine Arts, Boston [95]. It has the features:



Fig.31 Cartonnage coffin from the 25th Dynasty [95].

- The coffin was extensively decorated by coloured scenes of funerary objects and hieroglyphic text written within vertical white bounded columns. The coffin shows the deceased wearing a headdress and a broad collar. Again, the design and painting is more than wonderful reflecting the high quality of the ancient Egyptian art up to the Late Period.
- The cartonnage coffin is probably produced from linen (or papyrus) coated by plaster used starting from the First Intermediate Period to produce cartonnage for mask production [87]. However investigations showed that 'gum Arabic' was used as a

binding medium during the period 512-351 BC of the Late Period [96].

X. PAPYRUS PRODUCTION

The ancient Egyptians invented the papyrus writing scrolls since 2900 BC where papyrus blank rolls were discovered [97]. They used adhesive to make lengthy rolls up to 40 m [98]. Here are some examples of the ancient Egyptian papyrus rolls:

- **Example 1:** Fig.32 shows the blank papyrus paper produced during the 1st Dynasty of ancient Egypt (2900 BC) [99] , [100]. It has the features:

- The papyrus paper has a rectangular shape. No dimensions are given.
- The present location of the paper is not cited.
- It was found in the tomb of High Official Hemaka from the 1st Dynasty [100].

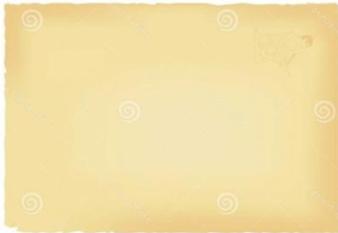


Fig.32 Blank papyrus from the 1st Dynasty [99].

- **Example 2:** Fig.33 shows the first known administrative papyrus paper written during the reign of Khufu, 2nd King of the 4th Dynasty (2589-2566 BC) [101]. It has the features:

- The papyrus paper was inscribed using a black pigment using the hieroglyphic script written within bounded columns.
- The present location of the paper is the Egyptian Museum, Cairo.
- Depending on the length of the papyrus roll, adhesive was used to join the papyrus standard segments.



Fig.33 Administrative papyrus from the 4th Dynasty [101].

XI. CONCLUSIONS

- The paper presented an intensive work for investigating the adhesives industry in ancient Egypt during the period from Predynastic to the Late Period.
- The ancient Egyptians used adhesives to support outstanding industries such as cartonnage and papyrus industries.
- The used inlays to enhance the beautiful appearance of some of their products such as amulets, pendants-pectorals, bracelets-armlets, finger rings, mummy masks and statues-coffins .
- The paper presented a unique style for the identification of the inlays using the available photos of the artifacts.
- The inlays were secured in positions using adhesives used in ancient Egypt for thousands of years.
- Amulets from the time of Naqada II/Naqada III, Middle Kingdom, 12th Dynasty and 18th Dynasty were investigated for inlays and adhesives use.
- Pendants and pectorals from the time of 12th and 18th Dynasties were investigated for inlays and adhesives use.
- Bracelets and armlets from the time of 4th, 17th, 18th, 21st and 22nd Dynasties were investigated for inlays and adhesives use.
- Finger rings from the time of 12th Dynasty and the New Kingdom were investigated for inlays and adhesives use.
- Mummy masks from the time of 1th Dynasty were investigated for inlays and adhesives use.
- Statues and coffins from the time of Naqada I, 5th and 12th Dynasties were investigated for inlays and adhesives use.
- Use of adhesives in the cartonnage industry was investigated through examples from the 3rd Intermediate Period-Late Period, 23rd Dynasty, 25th Dynasty and Late Period.

- Use of adhesives in the papyrus industry was investigated through examples from the 1st and 4th Dynasties.
- The timeline for adhesives use in the ancient Egyptian society was as follows:
 - Animal glue: since the Neolithic Period.
 - Resin: since the Neolithic Period.
 - Pinus genus resin: since the 17th Dynasty.
 - Lime plaster: since the 18th Dynasty.
- 28 examples were investigated to examine the adhesives application in ancient Egypt.

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DEDICATION



I dedicate this intensive work about adhesives industry in ancient Egypt to my colleague at the Department of Mechanical Design and Production, Faculty of Engineering, Cairo University Dr. Mohsen Elmahdy Said, Emeritus Professor of Solid Mechanics. For more than 50 years I know him as a great supporter to research and creative work with a pleasant character.

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