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Technical examination, elemental analysis and conservation of the arm of a colossal bronze statue from Aegion at the conservation laboratories of the National Archaeological Museum at Athens

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Abstract: The bronze arm, belonging to a colossal statue (presented by A. G. Vordos in this volume), was examined at the Chemical-Physical Research & Archaeometry Laboratory of the National Archaeological Museum (NAM) in Athens. According to prevailing methodology the examination comprised: macroscopic, microscopic and endoscopic examination, elemental analysis p-XRF, X-ray radiography, recording of ancient repairs. It is assumed that the arm was manufactured by the indirect lost wax casting technique and was found to contain an enormous amount of lead (av. 40.15 %), a fact that dates it to the late Hellenistic or Roman period. The arm was consequently conserved at the Metal Conservation Laboratory of the NAM and it has now been returned to the Ephorate of Antiquities of Achaia in Patras.

Keywords: technical examination, elemental analysis, bronze conservation, national archaeological museum

1. Introduction

This paper deals with the left arm of a colossal bronze statue from the Aegion Museum of the Ephorate of Antiquities of Achaia[1] with inv. no. AM 980 and NAM BE12-2018 (Fig. 1). The arm, including the forearm and hand, was introduced for conservation and examination at the Metal Conservation Laboratory of the National Archaeological Museum on June 29, 2018.

1 Of the Hellenic Ministry of Culture & Sports.

2. Technical examination/physicochemical investigation

2.1. Method

The technical examination was performed according to a protocol implemented at the NAM in consideration with in-house facilities,[2] which included: macroscopic inspection, microscopic documentation, radiography, qualitative/quantitative alloy analysis, thickness measurement, weighing, endoscopy and mapping of the ancient repairs.

Fig. 1. The bronze arm from Aigion (photo P. Feleris).

2.2. Results

2.2.1. Description-Dimensions

The arm is hollow and fabricated using the lost wax casting technique. The uniform thickness of the metal at the circumference of the shoulder (2.00 to 4.00 mm) and at the shoulder break (3.6–4.4 mm) indicate use of the indirect technique. No traces of refractory core were found inside.[3]

The arm has a linear length of 85 cm and a diameter at the end of the arm of 19 cm maximum in one direction and 15 cm minimum in the other. Externally from shoulder to elbow 35 cm, from elbow to end of forearm 41 cm and from end of forearm to bend of finger 25 cm. Internally from shoulder break to internal lock 24 cm, from lock to tip of forearm 31 cm and from tip of forearm to end of finger 25.5 cm. The arm weighs 11.16 kg.

Fig. 2. Fissure and large repair patch along the fissure in the middle of the forearm.

2.2.2. Technological evidence

An overflow of metal was observed on the inner wall of the shoulder and in the middle of the forearm transversely. This indicates a secondary fusion welding for local repair after the first cast. In fact, in the middle of the forearm, a transverse crack can be seen on the outside

2 For international standards in the examination of bronzes cf. Caumont et. al. 2007; Azéma et. al. 2012.

3 For the technology of bronze statuary cf. Mattusch 1996; Giumlia – Mair 2009.

which has rectangular repairs with plates in a row (Fig. 2).

On the inner walls near the opening of the shoulder, three square semi-deep holes were marked with metal displacement towards the inside (Fig. 3). These holes were opened in the wax with spacer nails in order to secure the clay core from dropping once the wax was melted. At the base of the little finger, a 2 × 2 mm square cross-section nail head is evident on the lock. It most probably served to attach the object that the hand was holding.

Fig. 3. Detail of spacer nail hole in the internal side of the arm.

Fig. 4. Evidence of wax leaves assemblage reproduced on metal.

Fig. 5. Square and rectangular repair patch.

On the inner surface of the shoulder, the assembly of the wax leaves can be seen as well as globular drops of wax reproduced on the metal (Fig. 4). In various places, due to casting imperfections, repairs had been made with square or rectangular plates 1.9 mm thick. A total of twenty-three patches were measured with maximum dimensions of 4.0 × 1.0 cm and minimum dimensions of 0.5 × 0.6 cm (Fig. 5). In two repairs the lamina has been lost and the notch remains, while in one both the lamina and the metal of the base are missing, resulting in a through rectangular lacuna. The palm has parallel incisions that indicate grinding marks possibly for passing the object it was holding. There are also two holes, one square and one circular apparently for fixing the object held (Fig. 6).

2.2.3. Radiography

The arm was X-rayed at the Physical-Chemical Research & Archaeometry Laboratory of the National Archaeological Museum (Fig. 7). An X-ray generator type ANDREX 3001 (ANDREX A/S, Copenhagen) was used with an operating voltage of 290 kV, a current of 4 mA and an exposure time of 20 min. The film to focus distance (ffd) was 90 cm and the film used was Agfa's Structurix D7/Pb. The X-ray was taken in three sections which were then digitally merged. The black cross lines and some water marks are due to the splicing of the negatives, so they should not be taken into account. What stands out is the overflow in the middle of the forearm and bubbles from the casting. Characteristically, the tips of the fingers are hollow and not solid, which shows perfection in the original model.

Fig. 6. Parallel incisions in the palm and two attachment holes, one square and one circular.

2.2.4. Elemental analysis

The metal alloy was characterized by X-ray Fluorescence Spectrometry[4] (p-XRF) and was found to be bronze with a low content of tin (Sn) (m.v. 6.71 %), a huge amount of lead (Pb) (m.v. 41.29 %) and a high amount of silicon (Si) (m.v. 7.05 %) (Tab. 1).

The analysis was repeated with the Brucker Tracer 5i portable XRF analyser of the Physical-Chemical Research & Archaeometry Laboratory at the National Archaeological Museum and the high content of lead was confirmed. It has been shown that copper alloys acquire a high lead content in the late Hellenistic and Roman imperial era with up to 50% lead.[5] Bronze pieces from the Hellenistic and Roman periods found in Rhodes also have a large content of lead.[6] The considerable amount of silicon found on the surface of the metal alloy is attributed to deposit of silicates in the burial ground.

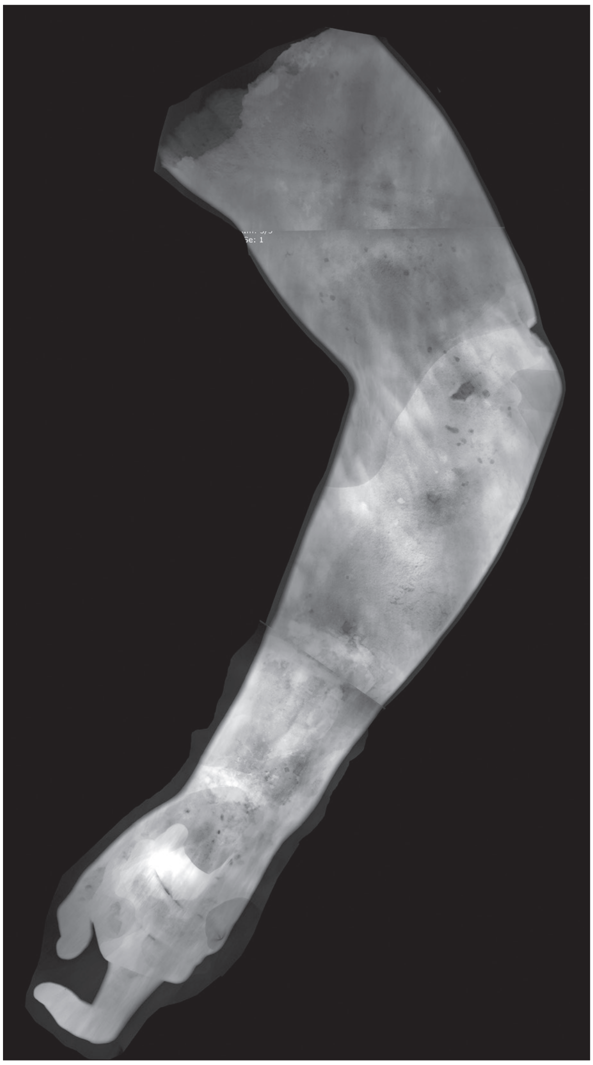

Fig. 7. X- Radiograph of the arm (the two cross lines are due to the merging of the three radiographs).

3. Conservation

3.1. State of preservation

The surface of the metal had a dark green patina of copper carbonate (malachite) with localized red areas of copper oxide (cuprite) and light green spots due to the so-called bronze disease (active corrosion). According to Dr. Vordos, the arm had been conserved in the National Archaeological Museum in the 1950s, but no in-

4 The analysis was made by Dr Effie Photos-Jones.

5 Craddock 1977; Giumlia-Mair 2015.

6 Zimmer – Μπαΐραμη 2008.

Tab. 1. Elemental analysis by p-XRF (E. Photos-Jones).

Reading No			Type	Pb	Cu	Si	Fe	Al	Zn	Sb	Sn	Zr
1782	arm, spot ana 1	βραχιονας	General Metals	37.86	54.55	2.13	0.36	< LOD	0.15	0.08	4.54	0.01
1783	arm, spot ana 2	βραχιονας	General Metals	63.53	15.11	11.39	4.89	1.66	0.09	0.03	1.81	0.02
1784	forearm, middle	μεσο του πηχη	General Metals	49.60	31.93	8.35	1.60	0.85	0.29	0.07	5.59	0.02
1785	forearm, external side	εξωτερικα, μεσο του πηχη	General Metals	29.48	50.49	8.80	1.49	1.78	0.18	0.07	7.39	0.02
1787	fourth finger	μεσο δακτυλο , εξωτερικα	General Metals	28.33	47.59	10.60	1.68	2.56	0.39	0.08	8.55	0.02
1790	spot ana 2, near wrist	....διπλα στον καρπο	General Metals	32.10	53.52	4.30	0.42	< LOD	0.15	0.12	8.43	0.01
1786	fourth finger, on area with evidence of flaking	τεταρτο δακτυλο, εξωτερικα	General Metals	52.35	34.41	5.43	1.45	< LOD	0.19	0.07	4.48	0.02
1788	index finger, spot with evidence of flaking	δεικτης , σημειο απολεπισης	General Metals	46.40	33.72	7.11	1.35	1.09	0.29	0.10	8.81	0.02
1789	spot ana 1 with evidence of mending, near wrist	αρχαια επισκευη στο μεσο του καρπου	General Metals	30.98	51.67	5.33	0.28	< LOD	0.15	0.10	10.82	0.02

formation was found either in the entry book or in the archive of the Metalwork Collection.There are heavy tool impacts (blows) with inward material retreat. These damages date either from antiquity, possibly in the case the statue was demolished, or when it was accidentally found (Fig. 8).

Inside the fingers there is still soil and roots as observed with the endoscope. The soil was not removed as it was difficult to reach.

3.2. Cleaning, stabilization, protection

Mechanical cleaning was performed with a scalpel, a glass brush, and a rotary tour with bristle brush and then wire nozzles.

The object was then exposed to infrared radiation to dry it and was stabilized using compresses impregnated with 5% Benzotriazole (BTA) in ethyl alcohol. Finally, the surface was coated with 10% Incralac™, an acrylic protective varnish.

3.3. Preventive conservation

The object must be protected from ambient moisture. It is recommended to enclose it in an airtight display case in the presence of silica gel desiccant or by installing a dehumidifier.

Fig. 8. Loss of metal due to a blow.

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