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STUDY OF THE QUATERNARY ALLOYS IN THE CAST OF THE EQUESTRIAN STATUE OF BARTOLOMEO COLLEONI BY ANDREA DEL VERROCCHIO (VENICE 1480) AVAILING OF EDXRF SYSTEMS

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ABSTRACT

The Bronze equestrian statue of Bartolomeo Colleoni by Andrea del Verrocchio, cast between 1466 and 1490 by Alessandro Leopardi in Venice, is composed of several parts connected together availing of casts-on.

The statue was analysed using a transportable EDXRF system in situ during the restoration of the monument, applied to 21 chosen areas, with the aim of characterising the alloys that compose the different parts of the statue.

The areas to be measured were chosen so as to include every sub-section of the statue, therefore every part underwent at least one quantitative analysis.

The metal used in the casts-on is a quaternary copper, tin, lead, zinc alloy, while the rest of the sculpture does not contain any trace of zinc, composed as it is of the classic ternary (copper, tin, lead) bronze alloy.

Considering the amount of metal required to make the casts-on, the shapes into which they were moulded and, therefore, the economic cost of every single cast-on, the artist's intention to exploit the strength of the copper alloys containing zinc to obtain sufficiently strong soldering between pairs of different casts is clear.

This fact and some direct observations of the inside the body of the horse corroborate the hypothesis that casting and assembling the monument required a very well thought-out organisation as well as experimental trial-runs by Andrea del Verrocchio before the cast could actually be undertaken.

INTRODUCTION

Restoration of the equestrian statue of Bartolomeo Colleoni by Verrocchio, standing in Campo Santi Giovanni e Paolo in Venice, provided a unique opportunity to carry out an in-depth study of the techniques used to produce one of the Italian Renaissance's greatest sculptural works.

The monument is composed of separate parts soldered together availing of a complex cast-on procedure.

After the fall of the Roman Empire, much of the ancient Greek and Roman metallurgic know-how was lost. This fact greatly limited the possibility of forging large-scale works except those comprising one piece only produced in a single cast.

At the time when the Colleoni statue was being forged, fifty years had already past since Donatello had cast the Gattamelata monument, similar in size and, like the Colleoni sculpture, composed of several parts.

At the end of the fifteenth century, smelters, in order to join two different casts, applied straightforward mechanical junctures or casts-on. The sculptures availing of this technique, including a number of works by Donatello, contain cast-on junctures, but the parts connected availing of this technique made no vital structural or static contribution to the sculpture as a whole.

Casts-on were used, traditionally, to repair bronze sculptural works (traces of this technique are to be found, for example, in the San Ranieri door of the Cathedral at Pisa made by Bonanno Pisano prior to 1180).

The Colleoni sculpture is composed of 16 parts, 8 each for the horse and the rider.

In order to assemble the sculpture securely, the parts had to occupy precise positions and the casts-on had to be homogeneous and strong, not only to guarantee that the parts fitted closely, but also to ensure that they would interact efficiently to support the monument.

The rider weighs 1300 kilos, and we have calculated that the horse must weigh another five thousand, roughly. The weight of the monument is discharged onto the pedestal where only three legs rest on the vertices of a rather narrow triangle. This is the area the smelter focused on when assembling the legs in order to guarantee the solidity required to sustain the entire sculpture.

MATERIALS AND METHODS

The huge equestrian statue of Bartolomeo Colleoni in gilded bronze is about 4 metres tall (excluding the base) and weighs about 6000 Kg. It stands in Campo Santi Giovanni e Paolo in Venice. The statue was sponsored by Bartolomeo Colleoni, a commander of the Venetian Republic. When he died, in 1475, he left part of his fortune (silverware, furniture, horses and 16.200 gold florins) to the Venetian State together with the explicit request to have a statue of himself erected in St. Mark’s Square. The Venetian *Signoria* decided, however, to erect the statue in front of St. Mark’s School, in Campo Santi Giovanni e Paolo.

To analyse the statue, a portable system was used (see Figure 1) working with a 35 kV X-Ray tube and a 0.2 mA-current tube; the detector is an SDD (Silicon Drift Detector) with a resolution of 150 eV at 6.4 keV. The areas analysed on the statue have a diameter of 2 mm each.

For greater, in-depth information regarding this technique and the Fundamental Parameter Method used to evaluate the spectra and generate the results provided in Table 1, please consult the references.

RESULTS AND DISCUSSION

In Table 1 the quantitative results of the measurements taken directly on the clean alloy with a 35 kV X-Ray generator are reported.

In Table 2 the measurement areas and the corresponding parts of the statue are reported.

The results of the survey show that the smelter opted for different alloys on the basis of their metallurgic characteristics.

In the casts-on of the three legs that rest on the base we found significant quantities of zinc, while this element was absent completely from the fourth raised one (left foreleg).

The body of the horse, comprising two parts, front and rear, was also assembled using casts-on. This part of the sculpture plays an important structural role because it supports the seated rider. In this area too the analyses revealed noteworthy amounts of zinc in the joinings.

The alloy used, containing between 3 and 13,2% of zinc, in the smelted state offers greater fluidity than the copper-tin alloy. Furthermore, as brass is considerably more resistant than bronze it is far less pliable.

Given the complexity and the technically advanced nature of the cast-on techniques availed of and the decidedly different kinds of alloy found in each cast-on, we may hypothesise that the smelter, when assembling the parts, decided to use an alloy containing zinc and small concentrations of tin for the precise purpose of making the joinings considerably more solid and resistant.

The efficacy of the casts-on at these points was of vital importance, because it would have been a problem to be obliged to carry them out more than once; therefore the greater fluidity of the brass was probably exploited by the smelter so as to encounter fewer problems while pouring.

The implementation of the cast-on system, explained in detail below, besides being carried out in stages, avoided the smelter the arduous task of finishing off the outer surfaces, given the immense difficulty of working on cold brass.

Ulterior confirmation of the deliberate use of copper-bronze alloys is provided by the fact that zinc is totally absent from the casts-on used exclusively to unite two adjoining pieces containing over 10% of tin. Furthermore, where the zinc is actually used, there is practically no use of antimony, a substance present in quantities varying from 1 to 5,5% in all the casts and casts-on containing no zinc.

We are therefore in the presence of a “special” alloy recurred to because of its specific characteristics.

Reconstruction of the Anchoring System Applied to the Separately Cast Pieces Availing of Casts-on

The following hypothesis is the outcome of an autoptic examination and of observations carried out during stratigraphic explorations of the inside of the horse. Here we came across data which permitted us to plot the temporal order of the operations carried out.

The construction of right hind leg of the horse was reproduced three-dimensionally.

Once the original leg had been cast separately, parts of the core were removed leaving a large iron support jutting out.

Having first attached the leg to the body of the horse a cylinder of fire-proof clay, later hardened by applying relatively moderate heat, was moulded around the support to increase its volume and enhance its resistance. The outer surface of this cylinder bears evident signs of firing through direct contact; at the bottom of the cast-on, in fact, several small fragments of charcoal were found.

Then a circular mass of wax of about one sixth of the diameter of the leg was applied. This was contained by small iron plates applied externally; the remaining space was filled with fire-proof clay partially hardened by the heat produced by the smelted bronze and fired later than the central heat-proof clay cylinder described above.

Externally the casts and vents were moulded in wax and covered entirely with a further layer of fire-proof clay. This way pouring was possible from outside and finishing work kept at a minimum.

This procedure was repeated five more times, probably pouring non adjacent sections first so as to be able to compensate from possible faults by cutting and remoulding (Figure 2).

Examination of the casts-on carried out on the three legs suggests that the technique was improved as work proceeded because the first one, probably the right front leg, appears much rougher and more uneven than the following ones.

How the Two Parts Composing the Body of the Horse were Soldered

The soldering of the two main sections of the horse was fundamental to the structural solidity of the entire monument and was carried out by recurring to a system of casts-on in molten bronze along the edges of the parts to be joined; the casts-on for the joining were carried out in succession, rotating the two adjoining sections of the body as the soldering proceeded; this, we believe, in order to effectuate the casts outside the horse's body. The body was assembled first while the legs, neck and tail were added later.

It was possible to reconstruct and plot the chronological order of the twenty casts-on thanks to the fact that they all matched reciprocally and to the clear orientation of the bronze trickles

Interpreting these signs logically we reached the following conclusion: (Figure 3)

The two parts of the body of the horse were aligned with the holes for the legs facing downwards and three plugs applied: plug G, surmounted by the encasing casts-on, plug R, which on the one hand fitted below the adjoining plug and probably below the other one too, block A, the first used to join the edge of the large opening beneath the saddle. These three casts-on acted as a temporary joining between the two parts of the body. Exploiting the vertical nature of the left haunch of the horse all the plugs used to solder that side (F, E, D, C, B in that order) were cast. Then the horse was laid on its right flank and the umbilical area's casts-on (Q, P, O, N, M, L, I, H) applied.

Finally the body was rotated and the last plugs (S, T, U, V) were used to close the right side.

The legs were added later, both to facilitate manipulation of the body and to permit the use of the openings to carry out casting operations.

In order to add the legs, the horse was placed in the upright position. This we believe seeing that the casts-on inside the legs appear to have been applied while the horse was in this position.

We can hypothesise that to obtain the wax moulds used for the smelting procedure a slightly "slimmer" model of the inside of the horse was made in fire-proof material, was covered in wax and forged later. The model was then cut into various sections before preparing the moulds and casting them so that the sections would fit as closely as possible after forging. The need to handle the parts to be cast separately it was necessary, from the core-formation and modelling phases on, to apply independent, removable iron supports to each part. At the top of the iron bars buried within the legs are eyelets which may have been used to unite the various removable structures of a sole separable model.

There are no evident traces of wax trickling inside of the horse such as to suggest indirect casting even if the inner surface of the horse presents none of the roughness typical of direct wax casting.

However, numerous very thin nails, completely absorbed by the bronze and driven in right up to the head, are clearly visible.

These may have acted as testers to measure the desired thickness of the wax. The fact that these nails were driven in up to the heads into the bronze and therefore into the wax, excludes their being used as divaricators as they do not connect the inner core of the cast to the outer mantle.

CONCLUSIONS

With a portable EDXRF system, the Fundamental Parameter Method and a multivariate cluster analysis, the different parts of the statue of Bartolomeo Colleoni in Venice were analyzed and grouped together. For the solders the lower melting temperature was obtained by availing of the zinc used in the brass or simply by adding it to the bronze alloys in order to produce a special alloy with certain characteristics. It was necessary that this alloy should be fluid when melted and resistant when cooled. The metal used for the cast-on is a quaternary alloy with copper, tin, lead and zinc, while the rest of the sculpture does not contain zinc at all, being composed, as it is of the classic ternary bronze alloy (copper, tin and lead). Suggestions are proposed for the procedure used by the smelter to build the statue.

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Number of	Cu	Sn	Pb	Sb	Ag	Fe	Zn
1	73.0	20.2	4.0	2.1	0.1	0.5	-
2	77.0	17.1	2.6	2.5	0.1	0.7	-
3	84.1	2.3	2.7	-	-	0.6	10.4
4	67.5	24.6	4.9	2.5	0.1	0.4	-
5	83.9	11.9	2.0	1.4	-	0.7	-
6	88.0	4.1	1.4	0.8	-	0.7	5.1
7	87.8	0.5	2.5	-	-	0.7	8.5
8	84.1	12.0	1.9	1.5	-	0.5	-
9	81.0	12.0	1.9	1.1	-	0.6	3.4
10	84.5	11.3	1.9	1.6	0.1	0.6	-
11	86.0	10.2	1.8	1.3	-	0.6	-
12	83.5	0.9	1.6	-	-	0.8	13.2
13	87.0	0.9	2.9	-	-	1.7	7.4
14	86.6	9.1	1.8	1.8	-	0.7	-
15	89.2	4.4	1.6	1.1	-	0.7	3.0
16	86.8	8.9	1.6	1.6	0.1	0.9	-
17	73.4	21.2	1.7	3.0	0.1	0.5	-
18	80.0	15.0	2.6	1.8	0.1	0.6	-
19	80.7	14.8	2.2	1.6	-	0.6	-
20	79.6	12.7	1.6	5.5	0.1	0.5	-
21	57.0	36.6	3.8	2.6	-	-	-

Table 1: Analyses of the equestrian bronze statue of Bartolomeo Colleoni.

number of	area
1	horse, right back leg
2	horse, right back haunch
3	horse, right back haunch, soldering area
4	horse, tail
5	horse, left back leg
6	horse, left back leg, under solder
7	horse, left side of the belly, soldering area
8	horse, left front leg
9	horse, left front leg soldering area
10	horse, front body
11	horse, right front leg, internal area under
12	horse, right front leg, soldering area
13	horse, right front leg, other soldering area
14	horse, neck, over soldering
15	horse, soldering area between neck and
16	rider, left calf
17	rider, dress in area of left haunch
18	rider, left hand
19	rider, left forearm
20	rider, chest in area close to the hand
21	rider, helmet.

Table 2: number of measurement and corresponding area.

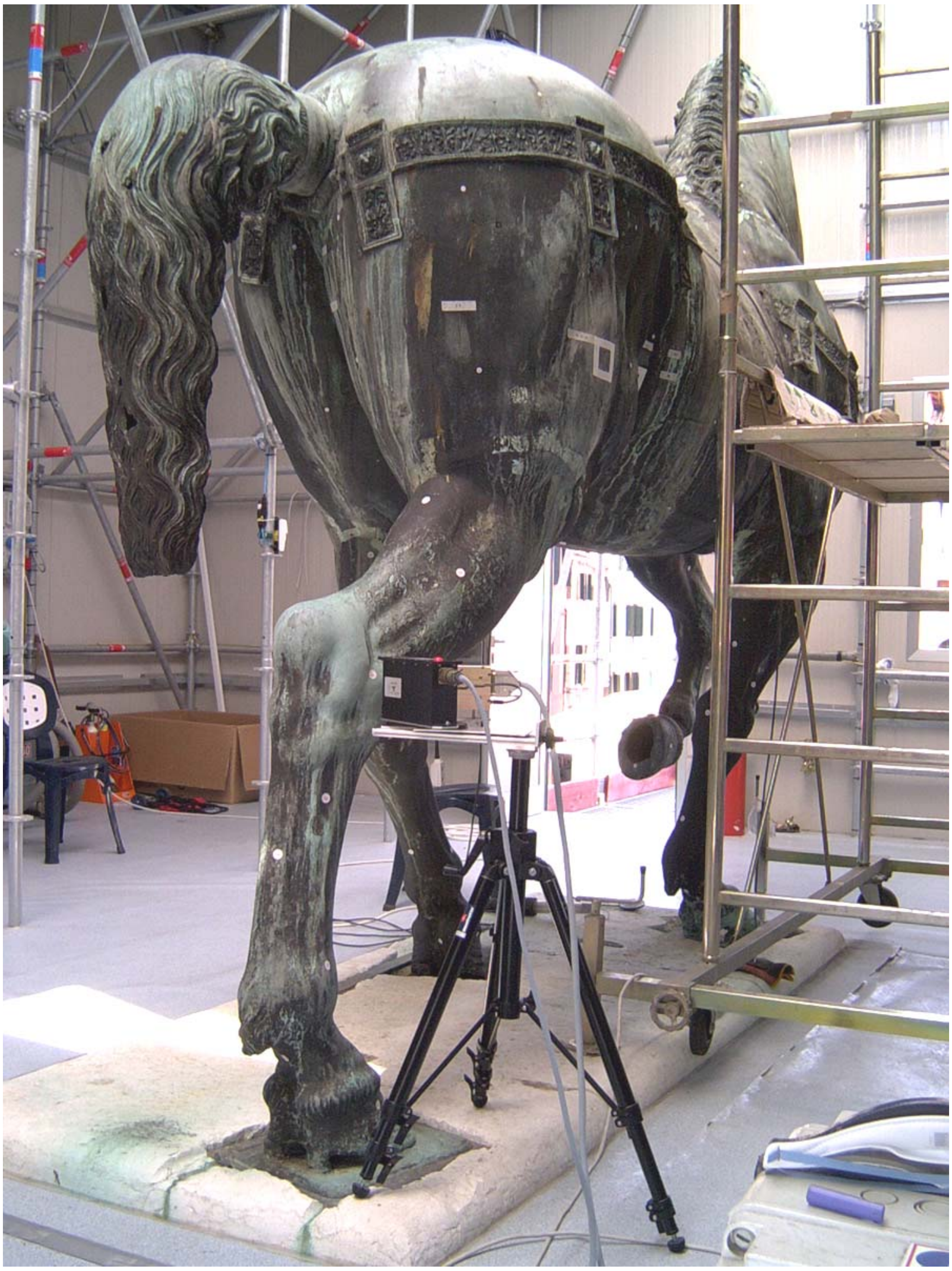

Figure 1: Rear view of the Colleoni horse during an EDXRF measurement availing of a portable system.

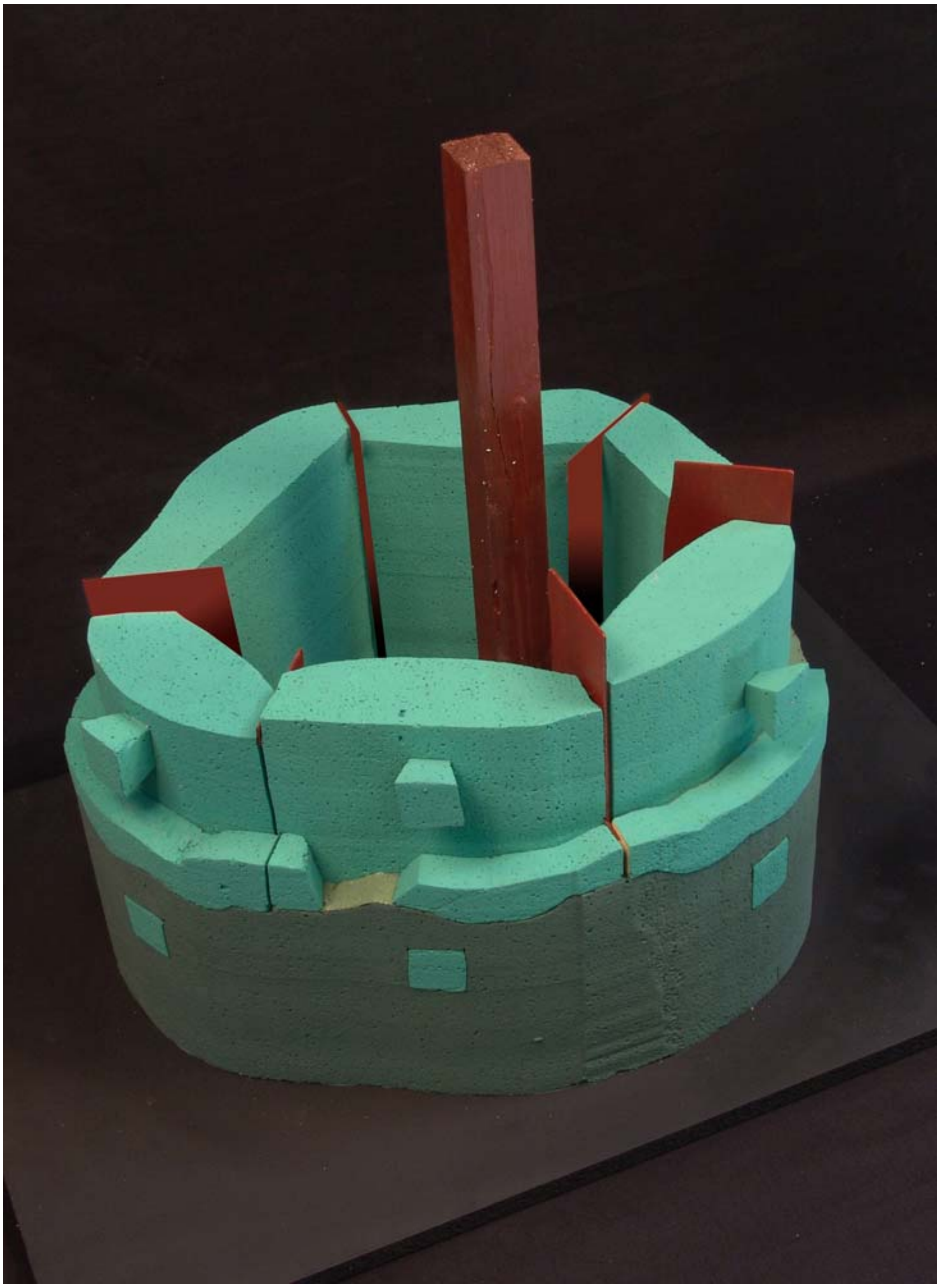

Figure 2: Three-dimensionally reconstruction of the casting of the legs.

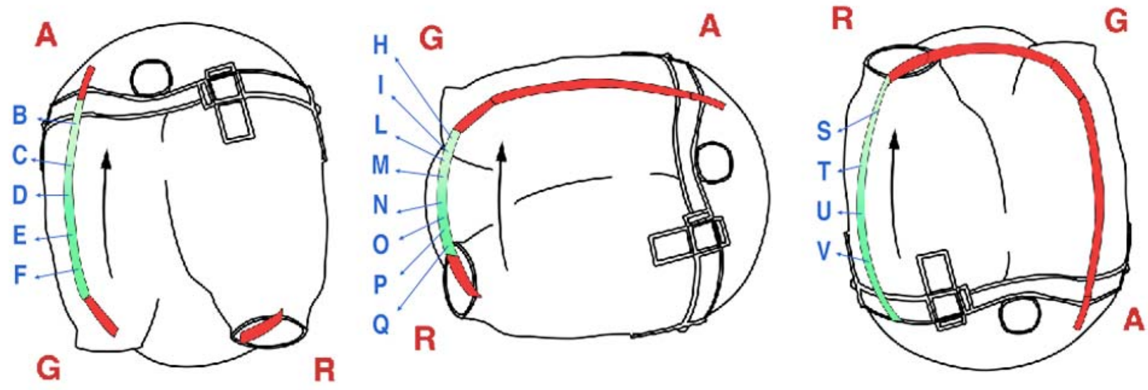

Figure 3: Chronological order of the twenty casts-on of the body of the horse.

Back to Top