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edited by Dávid Bartus, Zsolt Mráv and Melinda Szabó

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Some techniques for producing copper wire in late Classical and Hellenistic Macedonia

Rosemary A. Jeffreys
Independent researcher, Oxford, England
rosemaryjeffreys@talktalk.net

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Abstract: This paper discusses different techniques for making copper wire in the fourth and third centuries BCE in ancient Macedonia (Northern Greece). Wire was used to form stems on gilded wreaths, and to support berries, leaves and rosettes. Stems were made in one piece with the leaves, and are likely to have been formed in at least two ways: one involved cutting them out of sheet copper about 0.5 mm thick, which was creased and then hammered into shape; the other involves using copper rods 1mm square. Some of the square copper rods can be seen on the wreaths, and their regularity suggests they may have been formed on a swaging block. Berries were joined to the wreath circlets by round wires, formed in some cases, it is suggested, by hammering sheet metal around a central core; in other cases, these stems may have been formed by rolling a rod between stone slabs. No evidence, such as longitudinal striations, was found of drawing. Some examples of strip-twisted wire were found, but there are fewer cases of this than of wire formed by hammering. The most expensive gilded wreaths at Derveni, cist grave A, Phoinikas cist grave 5 and Sedes, sometimes had special features, such as gilded copper tubes ('branches') with smaller stems on either side, or square wires formed into spirals.

Keywords: wire, gilded wreaths, swaging, hammered, strip-twisted

Introduction

This consideration of copper wire arose from the author's study of gilded wreaths for her doctoral thesis.[1] She examined some 170 gilded wreaths at first hand, from four regions in Greece and Southern Italy. The earliest date to the first quarter of the fourth century BCE, and they continued in use until approximately the arrival of the Romans. They are mostly in fragments in museum storerooms, although a small number have been restored and placed on display (an example is at Fig. 1). Most have been cleaned, but have not necessarily received further conservation work. Gilded wreaths have been very little studied, partly because of their fragility and state of preservation, but their fragmented state makes it easier to study aspects like wire, since the fragments can be examined under the microscope and non-destructive analysis done without sampling. Gold wreaths are better preserved, and study of some aspects of them can help to understand the gilded wreaths.

In her thesis, the author divided the gilded wreaths into seven categories; similar materials were used for all of them but they were put together differently, and it was this which provided the basis for her categorisation.[2] The majority found in Macedonia, Northern Greece, were of her Type 2, which have copper leaves and stems and circlets of bone and wood, but there were two examples

1 Jeffreys 2019. An article summarising the main findings was published as Jeffreys 2022.

2 The seven categories are described in Jeffreys 2022, 231–235.

Fig. 1. Wreath from Aineia Grave III, MTh7570, on display (© Archaeological Museum of Thessaloniki, Hellenic Ministry of Culture and Sports – Hellenic Organization of Cultural Resources Development; photo by the author).

of her Type 1, the distinguishing feature of which is that one end of the stems was twisted around and anchored in the bone circlet. There were also a few of her Type 3, which had clay rosettes, and a few of her Type 6, which had painted clay flowers. It is the stems from the gilded wreaths, used to support leaves, berries, rosettes and flowers, which form the basis for this discussion, made from wires produced using several techniques.

All gilded wreaths known to the author have been excavated to date from graves, both inhumations and cremations, and were found with men, women, girls and boys. It can be seen from the other goods buried in the same grave that the deceased were wealthy. Most of the wreaths represent myrtle, but a few represent oak, ivy or olive. In Macedonia, many of the men were buried with weapons, as well as wreaths and other items, and are likely to have served with Philip II or Alexander the Great. The possible reasons for burying individuals with gilded wreaths are discussed elsewhere,[3] but they clearly include a wish to honour the dead. In some cases in Macedonia, in particular at Aineia III and Phoinikas cist grave 5, several wreaths were buried with the same individual, and in a few, gold wreaths were also found in the same grave, though whether this was to add to the honour bestowed or for some other reason is unclear.

3 See Jeffreys 2022, 247–251.

Chronology and location of wreaths found in Macedonia/Western Thrace

Excavations have not yet brought to light any wreath workshops, but it seems likely, in view of their fragility, that the wreaths were made locally to where they were buried, although there may be one or two cases of a shared workshop, as for example in the case of the very similar wreaths found at Derveni and Aineia, which are only about 50 km apart. However, the method used to make any of the wreaths could have been transmitted by travelling craftsmen or women, or by word of mouth.

The earliest gilded wreaths known to the author were found on the island of Thasos in the east and some 400 km away in what is almost certainly a royal grave at Aiani in the western part of Macedonia. Both were buried during the first quarter of the fourth century BCE and are of the type categorised by the author as 1. Relatively well-preserved wreaths of Type 2 dated to around the middle of the fourth century were found at Phoinikas near Thessaloniki (Fig. 2) and at Vergina/Aigai, in graves at Stenomakri Toumba, but the majority of gilded wreaths of this type were made in the second half of the fourth/early third century BC, and were buried in graves at sites in Macedonia and Western Thrace including Aineia, Akanthos, Derveni, Ano Komi, Sedes, Pella and Nikisiani. Sedes and Akanthos also had Type 3 wreaths and Akanthos and Karyochori had Type 6.

Methodology and summary of analytical results

The main method of study of the stems by the author was by observation of a selection of the wreaths from Macedonia involving use of a Canon SLR camera with a macro-lens and an optical microscope coupled to the camera as well as a digital microscope. She also did some analytical work on most of the wreaths which she studied for the doctorate. XRF (hand-held)

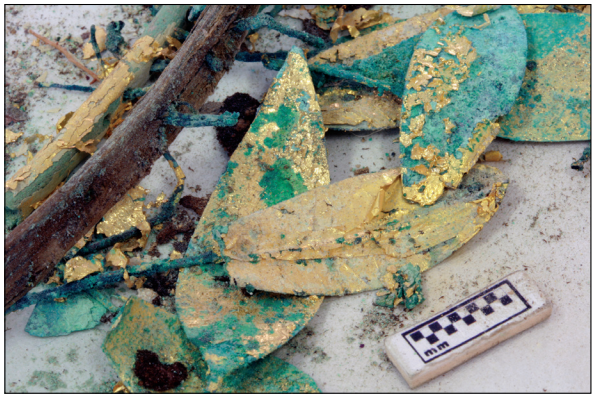

Fig. 2. Leaf and stem made of folded wire. Phoinikas, Grave 5, wreath 3, 3rd qu. 4th century (unnumbered, MTh) (© Archaeological Museum of Thessaloniki, Hellenic Ministry of Culture and Sports – Hellenic Organization of Cultural Resources Development; photo by the author).

Fig. 3. Berries mounted on round stems. Aineia, MTh 7571, 3rd qu. 4th century (© Archaeological Museum of Thessaloniki, Hellenic Ministry of Culture and Sports – Hellenic Organization of Cultural Resources Development; photo by the author).

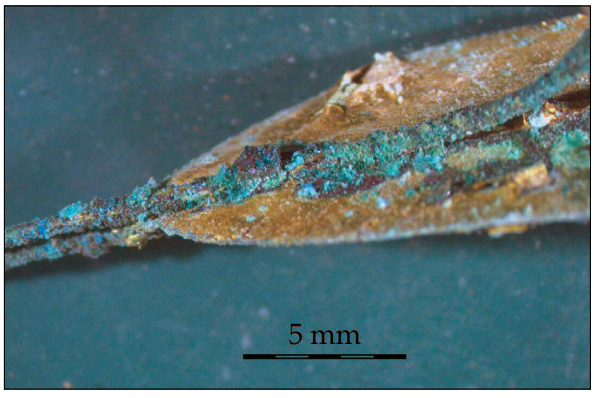

Fig. 4. Folded stem from Phoinikas Grave 3 (© Archaeological Museum of Thessaloniki, Hellenic Ministry of Culture and Sports – Hellenic Organization of Cultural Resources Development; photo by the author).

Fig. 5. Square stem from Derveni MTh D20 (© Archaeological Museum of Thessaloniki, Hellenic Ministry of Culture and Sports – Hellenic Organization of Cultural Resources Development; photo by the author).

Fig. 6. Leaf and stem from Derveni MTh D20 (© Archaeological Museum of Thessaloniki, Hellenic Ministry of Culture and Sports – Hellenic Organization of Cultural Resources Development; photo by the author).

Fig. 7. Bronze anvil, BM 1872,0329.16 (© Trustees of the British Museum. Note the groove which could have been used for shaping a small rod to the right).

was used on virtually all the wreaths; a selection from Macedonia were also examined using micro-XRF or SEM/EDS. There was not time, within the parameters of the doctoral study, to seek sampling permission and metallographic examination was not done.

In the analytical work, the leaves and stems of virtually all the wreaths were found to be copper and the berries, rosettes and flowers were clay. Bone, wood and lead were used for the circlets and thin gold leaf, which was almost pure gold, was applied on most of the surfaces. Table 1 shows a selection of results from all the regions within the scope of the thesis which are relevant to study of the stems, from which it can be seen that the copper used was fairly pure, with no more than a trace of lead and no tin.[4] The results from analysis of the leaves are included because these were generally made in one piece with the stems. The author's results are consistent with those of other researchers, including Asderaki and Rehren, who studied fragments of wreaths from Demetrias in Thessaly.[5]

In the view of the present author, the wreath makers chose to work in copper because it is more malleable and easier to cut than bronze.

Different techniques used to make wire

Most studies of wire have been done on gold, which does not corrode like copper, but examination of the copper stems on the gilded wreaths has produced some interesting information.

The wire stems were used to support leaves, berries and sometimes rosettes or flowers. One end of the stem was placed in a hole in the circlet(s) and sometimes bent back. The stems on the finer wreaths were generally gilded, and the leaves always were. The gilding technique used on these and all other elements of the wreaths involved applying gold leaf which was about

4 The full results of the analytical work can be found in Jeffreys 2019, Vol. I, Chapter 6. In only two cases, from Pergamon, was bronze detected, on wreaths which must have been used on statues and in the author's view date to the very end of the period.

5 Asderaki – Rehren 2008, 508–509.

Fig. 8. Round stem from Sedes Γ, late 4th/early 3rd century (© Archaeological Museum of Thessaloniki, Hellenic Ministry of Culture and Sports – Hellenic Organization of Cultural Resources Development; photo by the author).

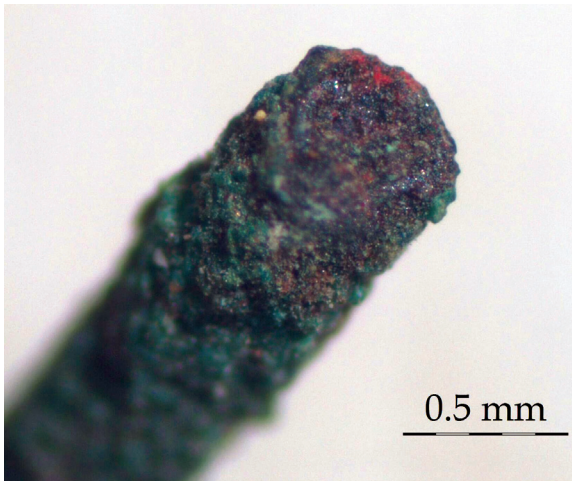

Fig. 9. Round stem from Derveni B, late 4th/early 3rd century (© Archaeological Museum of Thessaloniki, Hellenic Ministry of Culture and Sports – Hellenic Organization of Cultural Resources Development; photo by the author).

1 micron thick above a clay coating (Fig. 2).[6] The wire was generally under 1mm square or in diameter, but on some wreaths, as at Sedes, it was larger (up to 2 mm square or in diameter) to support large rosettes. Ogden comments that copper wire was generally made by hammering[7] and this is borne out by the present study.

The leaves were made of sheet metal about 0.5 mm thick and weighed only a few grams, as did the clay berries, but the rosettes were much larger and many times heavier. The leaves were made in one piece with the stems, for which no soldering was required, but the stems were attached to the clay berries and rosettes by a hole in the clay which was probably pierced by the stem while the clay was still soft (Fig. 3). The berries were not necessarily fired, but could have been left to dry in the sun.

Some of the stems with the leaves were rounded, as on the examples from Phoinikas (Fig. 2, Fig. 4). It seems that they were cut from a single sheet of metal, about 0.5 mm thick, which consisted of a rectangle at one end and a leaf shape at the other. A groove was made through the centre of both rectangle and leaf, as can still be seen in Fig. 2. The rectangle was then hammered into a C shape —what Oddy calls 'folding'.[8] The copper would have had to be annealed at all stages and it is suggested that the hammering would have been done against a hard core, which could have been of bronze or iron. The opening along the length of the stem is clearly visible in Fig. 4. This would obviously have been extremely fine work, given the dimensions involved.

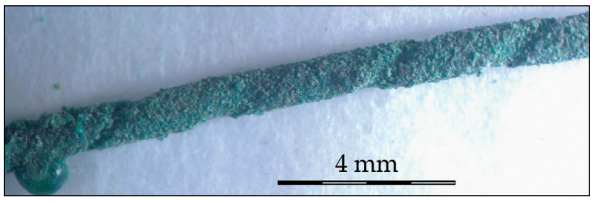

Fig. 10. Strip-twisted wire from Sedes, last qu. 4th c. MTh (© Archaeological Museum of Thessaloniki, Hellenic Ministry of Culture and Sports – Hellenic Organization of Cultural Resources Development; photo by the author).

Some of the stems are square, and in this case the starting point would have been a copper rod which was square in cross-section (Fig. 5), one end of which was hammered out to form a leaf and the other end left square (Fig. 6).

6 For discussion of the gilding technique see Jeffreys 2022, 243–245.

7 Ogden 1982, 51.

8 Oddy 1987, 177, Fig. 1.

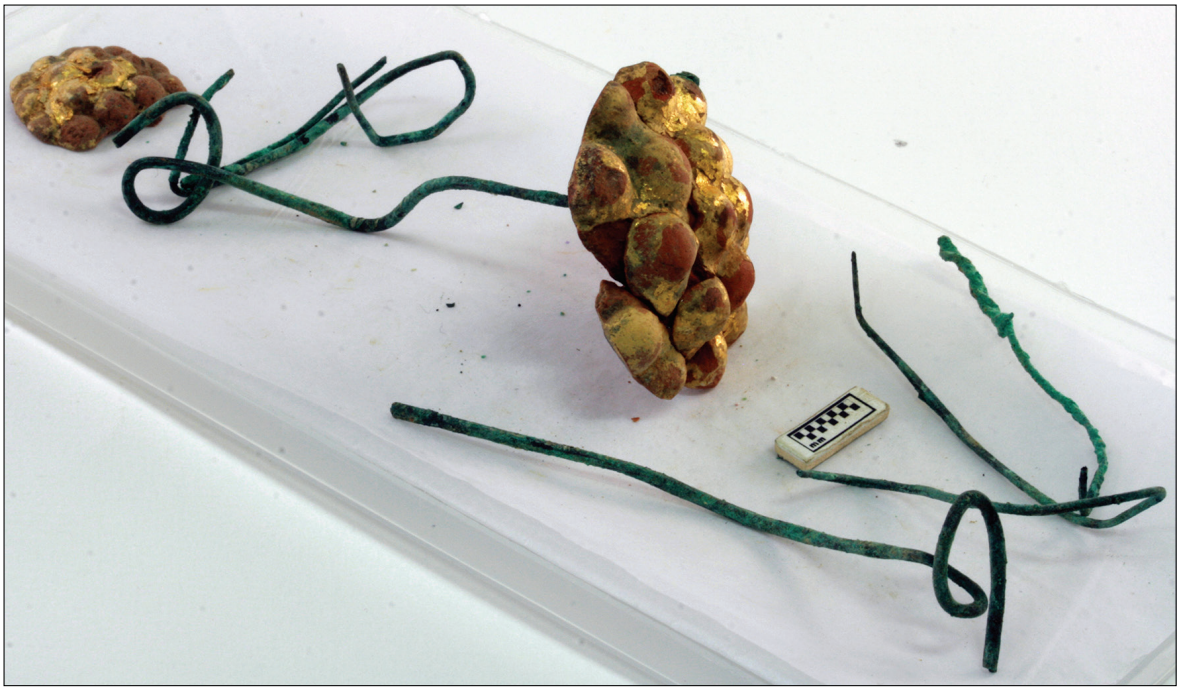

Fig. 11. Stems around 2 mm square in cross-section from Sedes, last qu. 4th c. MTh. 5535 and 15370. Rosette and stem assembled by the author for the purpose of study.

The square stem in Fig. 5 is very even, suggesting that it may have been made by swaging rather than a chisel.[9] This is a process which generally involves hammering or pressing a piece of metal into a groove on an anvil. Nowadays it is done using a pair of grooved tools, but it seems that in the Bronze Age, only one tool, an anvil, was grooved, which was struck from above by a hammer.[10] Oddy commented in an article published in 1977 that a swage block may have been used to assist in the production of wire by hammering, but observed that the origins of the swage-block were obscure.[11] Since then, more research has been done, including that by Ehrenberg. She studied anvils from Northern and Central Europe, and observed that many would have been melted down, but that in any event small bronze anvils would not have been common since they would only have been used for fine and delicate work.[12] The author has not so far been able to discover any evidence of small grooved anvils from Greece, but it seems possible that they were used there, since some complex anvils with a groove (semi-circular, V or W in cross-section) have been found further north, dating to the Bronze Age,[13] and there is evidence of the technique being applied in Egypt. Ogden discusse how a swaging technique might have been used to produce some types of wire and illustrate this by a swage block dating to the Late Bronze Age from Mâcon which has a semi-circular groove in which the rod would have been shaped (Fig. 7).[14] He also refer to some unfinished pieces of gold jewellery from Egypt, dating to Ptolemaic times, which he comment show microscopic evidence for having been swaged but which is not visible in the accompanying pho-

9 Ogden 1982, 52.

10 Ehrenberg 1981, 20.

11 Oddy 1977, 83.

12 Ehrenberg 1981, 14.

13 Ehrenberg 1981, 20.

14 BM 1872, 0329.16, illustrated in Ogden 1982, Fig. 4.36. See also Ehrenberg 1981, 20; the block from Mâcon is no. 24 in her article.

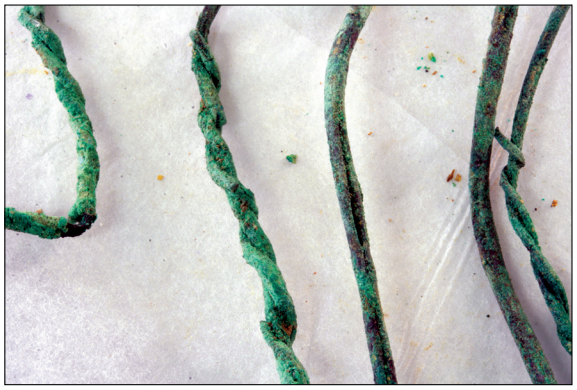

Fig. 12. Two strips of wire twisted together (wires second from left and far right) from Sedes. In centre, piece of folded wire. The wire second from right appears to be two pieces of wire laid alongside. MTh 15370 (© Archaeological Museum of Thessaloniki, Hellenic Ministry of Culture and Sports – Hellenic Organization of Cultural Resources Development; photo by the author).

tograph.[15] Looking closely at the cross-section in Fig. 5, showing a square stem from Derveni, a slight overhang is visible on the top edge, which would be produced if the wire was a little larger than the groove, providing support for the suggestion of swaging.

On the berries, round stems were used which can be seen to have been made in several different ways. Some appear to have started with a strip of sheet metal which was hammered into a tube[16]—the 'folding' method put forward by Oddy. This could then have been rolled between stone slabs, perhaps with an organic substance that has now disappeared. This method would leave a hollow core. If the edges of the long sides overlapped, the sheet metal would have formed into a shape like a G or the numeral 6 in cross-section. A possible example of a stem made in this way is from Sedes (Fig. 8). The outer part of the tube is copper as is the inner core, with corrosion in between.[17] As will be suggested below, a piece of thread would have been wrapped around the tube to give support while it was being rolled. I suggest that stone slabs would have been used for rolling in order to give some friction and stop the metal sliding.

Alternative methods might have been to roll a square copper rod between stone slabs or hammer

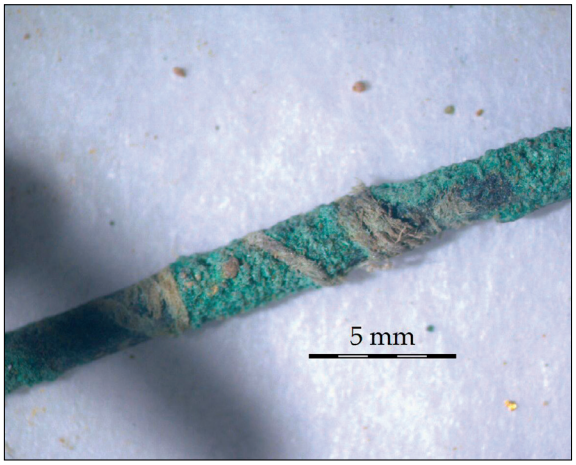

Fig. 13. Detail of stem from Sedes Γ with original linen thread which has been flattened. MTh 28254 (© Archaeological Museum of Thessaloniki, Hellenic Ministry of Culture and Sports – Hellenic Organization of Cultural Resources Development; photo by the author).

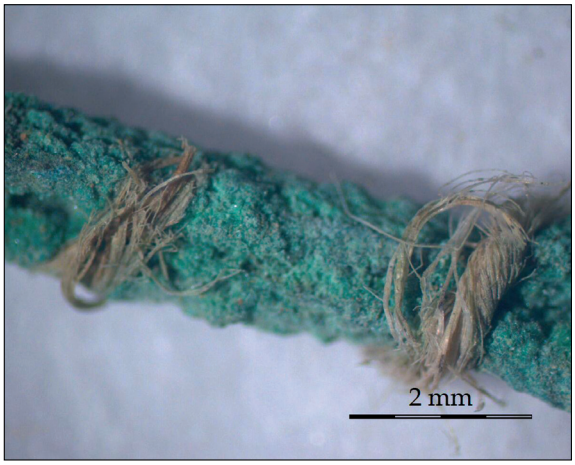

Fig. 14. Detail of thread used to bind two stems together on wires from Sedes Γ. MTh 28254 (© Archaeological Museum of Thessaloniki, Hellenic Ministry of Culture and Sports – Hellenic Organization of Cultural Resources Development; photo by the author).

15 Ogden 1982, 52, Fig. 4.39 showing a ring (BM 1887, 0101.518) and an unfinished necklace (BM 1887, 0101.570), both made from square wire.

16 See Ogden 1982, 48; Oddy 1987, 177.

17 A photomicrograph of a similar stem in cross-section can be seen in Asderaki – Rehren 2008, 510, Fig. 7.

copper in a rounded groove on a swaging block,[18] either of which would leave a solid core. It is difficult to be sure because of the corrosion, but the stem from Derveni in Fig. 9 appears to have a solid core and could have been made in this way.

The possibility that the rods were drawn through holes in beads cannot be completely ruled out, but the author did not find any evidence of this such as longitudinal striations. The wire did not need to be of any great strength, so it seems unlikely that the method of drawing suggested by Özşen and Willer for iron chain mail (of a later date) would have been used.[19]

Some examples of twisted wire were found with berries, though this was not common. The method of making strip-twisted and block-twisted gold wire is too well known to dwell on here, but in brief, strip-twisted wire was formed by wrapping a strip of sheet metal around a core and block-twisted wire by twisting a copper rod.[20] The author found examples of strip-twisted copper wire on wreaths from Vergina dating to the mid-fourth century BC and also at Sedes (Fig. 10), Nikisiani, Aiani and Ano Komi, as well as one piece of twisted wire which appears to have a solid core at Pella. The craftsmen working at Pella and Vergina, both royal cities, would have had access to the workshops where gold and copper wire were being produced for several purposes including jewellery and they may have obtained the berry wires ready-made.

At Sedes, some of the wires used on wreaths were larger, about 2 mm square and several different methods seem to have been used there to make strong stems for rosettes (Figs 11–12). There are examples of two wires twisted together (Fig. 12), and it looks at first sight as if the craftsman was developing a way of making strip-twisted wire, but since there is evidence of strip-twisted wire on a wreath from the same grave, it is more likely that he or she was experimenting with different kinds of stems in order to provide support for the heavy rosettes.

Use of thread

A feature of the gilded wreaths is the thread sometimes found wrapped around the stems, which was used not only to bind several stems together but also around individual stems. The original linen thread has survived probably because it was mineralised in part, a gradual process whereby at least part of the organic material is replaced by copper or iron corrosion products; the copper salts are toxic to micro-organisms and help to preserve the organic matter.[21] A well-preserved example on a single stem is at Fig. 13. This use of thread on single wires is interesting. I suggest that it was used in the manufacturing process to give more friction and stability when the wire was being rolled. The thread shown in Fig. 13 seems to have been flattened by strong pressure and can be contrasted with the thread used to bind several stems together shown at Fig. 14 which does not have similar flattening. In many if not all cases the threads would have been kept in place for added tensile strength while the wreaths were assembled, partly

Fig. 15. Wires from Derveni D which appear to have been bound with thread, last qu. 4th century (MTh D20) (© Archaeological Museum of Thessaloniki, Hellenic Ministry of Culture and Sports – Hellenic Organization of Cultural Resources Development; photo by the author).

18 See Ogden 1982, 48.

19 Özşen – Willer 2016.

20 See for example Swaddling et al. 1991, 9–11, Fig. 17.

21 Anheuser – Roumeliotou 2003, 23.

because the stems needed to be handled and bent into position. If the stems were gilded, the gold leaf was applied on top of the thread which would then barely have been visible (Fig. 15).

Special features

Special features were found on some of the most expensive fourth c. BC wreaths. In addition to gilding on the stems, mentioned above, spirals, made of square wire, were used in some places including Phoinikas to support some of the berries (Fig. 16). The spirals appear to have been used for purely decorative effect, but would have taken time and skill to make.

Derveni Cist Grave A contained a gilded oak wreath buried with a wealthy man which had oak

Fig. 16. Gilded spirals made from square wire. Phoinikas cist grave 5, wreath 1. 3rd qu. 4th century (© Archaeological Museum of Thessaloniki, Hellenic Ministry of Culture and Sports – Hellenic Organization of Cultural Resources Development; photo by the author).

leaves and complicated stems[22]. Some of these are made of tubes with smaller stems coming out of the main 'branch' (Fig. 17). The tubes were made of sheet copper. The sheer skill required to make something of this size and intricacy can only be admired.

Fig. 17. Gilded tubular (branch) with slender stems inside. Derveni cist grave A, last qu. 4th (© Archaeological Museum of Thessaloniki, Hellenic Ministry of Culture and Sports – Hellenic Organization of Cultural Resources Development; photo by the author).

Conclusions

The wires used on stems to support leaves, berries and rosettes on gilded wreaths from the fourth century BCE in Macedonia were produced using several different methods. Most of the methods seem to have involved hammering and creasing, with a few examples of twisting, and all would

22 Jeffreys 2019, Vol. 2, 44–50.

have involved rolling between slabs. These methods are proposed following close observation of the actual stems. It is hoped that the suggestions made here will be confirmed in experimental work, which the author intends to pursue at a later stage.

Acknowledgements

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Tab. 1. Table of selected results from analysis. The results of the analysis using µXRF and SEM/EDS are given in weight percent but because of the uneven surfaces are semi-quantitative. They have been normalised to 100% and calculated to one decimal point, averaging several iterations. Results for aluminium and silicon on these surfaces obtained from the HHXRF analysis are unreliable.

Method	Wreath	Date	Al	Si	Ca	Fe	Cu wt%	Sn	Au Wt%	Pb	Ag	Hg	Additional elements
Leaves from gilded wreaths (substrate)													
HHXRF	Olynthos	First half 4th			tr	tr	✓	×		×			
HHXRF	Potidaia	Late 4th	✓	✓	✓	tr	✓	×	✓				
µXRF	Phoinikas Cist Grave 3	2nd qu. 4th					99	×	1				
µXRF	Phoinikas Mac. Tomb	After 320			Tr		98	×	2				
SEM/ EDS	Aineia Grave 3 Anth 7572	3rd qu. 4th			0.7		97.4	×	1.9				
SEM/ EDS	Derveni D	After 320	2				98	×					
SEM/ EDS	Phoinikas Cist Grave 5 wreath 3	2nd qu. 4th	0.5	0.9	1.4	2.6	94.1	×					
SEM/ EDS	Phoinikas Cist Grave 5 wreath 3	2nd qu. 4th		0.5			82.7	×	3.3				Cl (8.4) Mg (0.4) S (3.2)
Stems													
HHXRF	Thessaly Pilaf Tepe NAM 12081	2nd q.3rd	ns	ns	x	tr	✓	×	✓	×	×	×	
	Taras MaRTA 51681	2nd half 3rd				✓	✓	×	x	tr			
	Taras MaRTA107617	2nd q.3rd					✓	×		tr	×	×	

(✓ – indicates presence, × – indicates not found, tr – is trace)