Antichthon, 50 (2016) 17–32
doi:10.1017/ann.2016.3

An Experiment in Manufacturing Blanks and Striking Coins*

ABSTRACT

In the second half of the 6th century BC four South Italian Greek colonial cities – Sybaris, Croton, Metapontum and Caulonia – were minting silver-copper alloy coins, all in the incuse fabric, with the same weight standard of c. 8gm. These incuse coins were to remain in production at Croton and Metapontum for the next 100 years.

Coins hoards indicate that these four cities began minting their coinage at the outset as very fine, artistic – even exquisite – objects of fine craftsmanship. Each coin was thin (1mm), broad (30mm) and of a consistently uniform weight and diameter, and each coin was struck between dies of exceptional quality. During subsequent decades the diameter of the coinage was progressively reduced.

At Monash University in 1980 we conducted experiments in coin manufacturing to determine how the minters at Croton in the 6th century produced these thin, incuse coins from only a small amount (8gm) of silver alloy, how they maintained a consistent weight standard across a century of minting, and why they progressively reduced the size of their coins during this period.

It is well-known that the manufacturing processes of objects made from metal alloys can be revealed by examining their crystal structures.

In our experiments in manufacturing broad, thin 'Monash coins', we examined the crystal structures at various stages throughout the process. To do this we made coin blanks of various diameters, all made from 8gm of silver-copper alloy. These blanks were subjected to hardness tests and photographs were made of the alloy's crystal microstructures. 'Coins' were then minted by striking blanks between two manufactured replica dies, and their microstructures were compared with the microstructures of a genuine Croton incuse coin fragment.

This is the first time these results have been published.

* I would like to acknowledge Mr Gary See Toh Lock for his work in carrying out the experiments with Ag4Cu and producing the micrographic structures for analysis at Monash University in 1980, and thank him for allowing me the use of his images in my PhD thesis, which are reproduced here in Figs. 6-13 and 15-20, and for his original tables from which Graphs 1 and 2 were derived. I also thank Dr Dick Jago of the Metals Department of Monash University (1980) for assisting me in the interpretation of the microstructures, and the late Dr Colin Kraay of the Ashmolean Museum for his advice and assistance in providing the Croton coin fragment for analysis in 1980.

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The Coinage of Croton[1]

The incuse[2] coinage of Croton consists of different coin types that were produced during a century of minting in which the first coins were of exquisite workmanship and artistic quality. These were the early 'Tripod'



Fig. 1
30mm 'Tripod' coin



Fig. 2
28mm 'Heron' coin



Fig. 3
28mm 'Crab' coin

series of 30mm diameter (Fig. 1) that were later reduced to 28mm diameter and then divided into two series – termed 'Heron' and 'Crab'[3] incuses – ranging from an initial 28mm diameter (Figs 2 and 3) to 18mm. Somewhere

[1] This paper is a revised version of Chapter 4 in my PhD thesis: R.J. Williams, 'The Incuse Coinage of Croton, 6th and 5th Centuries BC', Monash University (1983), which made a detailed study of the entire extant Croton coinage. Much of the interpretation of the Croton incuses in this paper is derived from that study.

[2] 'Incuse' is the term used to describe a coin that has a raised image (in relief) on the obverse and an almost identical image impressed or incused into the reverse. For an introduction to the incuse coinage of South Italy, see N.K. Rutter (ed.), *Historia Numorum Italy* (London 2001). The incuse coinage may have been derived from the deliberate and resourceful process of 'hubbing' reverse dies from pre-cut obverses. To hub a reverse die from an obverse die, the image is first cut into the obverse die face, then an uncut softened reverse die is driven into the image on the obverse die, so transferring an identical image embossed (raised) onto the reverse die. This reverse die then produces coins with an incused image. With the Croton (and the other South Italian) incuses, inscriptions and sub-symbols were then cut into the fields of both dies before they were hardened, so producing, at Croton, the incused tripod symbol on the reverse of the minted coins with the raised inscriptions and sub-symbols in both the obverse and reverse fields of successive coin issues. For further discussion on hubbing dies, see G.F. Hill, 'Ancient Methods of Coining', *Numismatic Chronicle* 5th Series Vol. 2 (1922) 1-42.

[3] These coins depict the tripod with an added heron or crab sub-symbol (raised) in the field.

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in the same period another series, the 'Eagle' incuses, was introduced (Fig. 4). As coin diameters reduced, the quality of the workmanship and of the artwork diminished (Fig. 5).



Fig 4
26mm 'Eagle' coin



Fig. 5
18mm stylized 'Heron' coin

The 981 extant genuine Croton incuses (which I examined in 1983)[4] have an average weight of 7.81gm and standard deviation of 0.41.[5] It can be assumed, therefore, that a consistent method of producing each blank close to a constant weight during a century of minting at Croton must have been employed.[6]

Furthermore, since all the coins have a similar weight (and therefore similar quantity of metal), a 30mm diameter coin blank is thinner than a 22mm diameter coin blank. 8gm of silver alloy, when minted as a 30mm coin, is about 1.1mm thick, while 8gm of the alloy minted into a 22mm coin is about 2.1mm thick. Thus the desired diameter of the coin determines its

[4] My study (Williams, n. 1) relied on individual coin images, together with weight and provenance, collected from numerous sources, including published volumes of *Sylloge Nummorum Graecorum*, articles, sales catalogues, and museum and university collections. Exact one-to-one images were printed to ensure meaningful comparisons could be made. All weight statistics in the study relied on the weights as recorded in the museum or published notes for each coin.

[5] A standard deviation of 0.41 means that 667 Croton incuse coins (68% of the 981 coins) lie within the range 8.82gm (7.81gm + 0.41gm) and 7.40gm (7.81gm – 0.41gm). This is a reasonably low standard deviation, given that there are many in the collection that are corroded and worn, and indicates that most blanks were produced fairly close to the average weight. See http://libweb.surrey.ac.uk/library/skills/Number%20Skills%20Leicester/page_17.htm, for explanation and application of standard deviation.

[6] The other incuse minters show similar consistent standards: Caulonia 7.91gm, standard deviation 0.30 from 194 coins; Sybaris 7.88gm, standard deviation 0.30 from 49 coins; and best of all, Metapontum 7.96gm, standard deviation 0.19 from 327 coins. Williams (n. 1), chap. 5, 125, n. 44.

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thickness. The results of the experiments carried out at Monash University Metallurgy Department showed that it is the thickness of the coin blank that determines the processes required to make it ready for striking into coin.[7]

The Alloy

The genuine Croton incuse coin fragment from the Ashmolean Museum Oxford (Fig. 6) was examined and found to be made of 96% silver (Ag) and c. 4% copper (Cu), which is referred to as Ag4Cu.[8] The alloy may have been naturally derived in antiquity from the mined silver ore. All 'Monash coins' were made from our own manufactured Ag4Cu alloy.



Fig. 6
19mm Croton incuse fragment after slivers removed and mounted in resin for etching.

Preliminary tests showed that, when Ag4Cu is melted in normal atmosphere, it absorbs a large quantity of oxygen and expels the same amount explosively when it solidifies, leaving the surface of the alloy covered in small craters (Fig. 7). Melting the alloy in a carbon environment

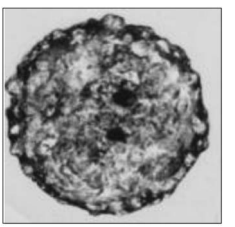


Fig. 7
17mm cast Ag4Cu pellet (X 2) which has solidified in a non-reducing atmosphere.

[7] The experiments were carried out by Gary See Toh Lock as part of his honors course Fourth Year Project in the Engineering Department at Monash University, under the supervision of Dr Dick Jago, in conjunction with my doctoral research on the coinage of Croton.

[8] The coin was examined in an X-Ray diffraction machine. It bombarded the fragment with electrons, captured the particles so emitted, interpreted from which metals these particles had been emitted, and graphed the result. Later, a sample sliver of the coin was mounted in resin, and the edge polished down to a flat surface, etched and photographed under a photographic microscope. See Fig. 17 below.

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(on a carbon block) provides a reducing atmosphere that prevents oxygen absorption.[9]

Creating the Blank

In antiquity a coin was made when a metal blank was placed between an obverse die (cut into an anvil) and a reverse die (cut into one end of a punch), and the opposite end of the punch then struck with a force. The blank was manufactured into an acceptable size and shape for producing the coin, and the dies were cut by hand by a die-engraver. The dies had to be cut to the right size to fit the desired coin blank; conversely, there is no point producing a pair of dies if you cannot produce blanks of sufficient diameter that will fit them.

To test if 8gm of molten Ag4Cu spreads to an acceptable 30mm blank for the production of the earliest incuse coinage,[10] 8gm of our pre-weighed alloy was melted and poured onto a flat carbon surface.[11] It solidified into a 17mm (maximum) pellet – a flattened spheroid (see Graph 1, p. 31).[12] There is a rapid loss of heat energy resulting in rapid solidification when the 8gm of molten alloy at 1050°C is poured out onto the flat surface and exposed to ambient temperature.

This 8gm 17mm diameter spheroid has to be enlarged in some way to enable the production of larger coins.[13]

Attaining Consistent Weight of 8gm of Ag4Cu

We tested another plausible method of creating the pellet and, at the same time, achieving consistent weights. We prepared 'split-moulds' (Fig. 8, next page) by carving spheroidal cavities into two separate carbon blocks, which were then joined together with the cavities aligned. The molten metal alloy was then poured into this split-mould, which was then separated after the metal had

[9] For observations of this phenomenon, see http://www.isoflex.com/silver-ag.

[10] This part of the experiment is of importance. C.F. Elam, 'An investigation of the microstructures of fifteen silver Greek coins (500 to 300 BC) and some forgeries', *Journal of the Institute of Metals* 45 (1931) 111-16, notes that her microstructure images of a genuine 28mm Sybaris coin (?520 BC) indicate that it had been struck on an as-cast blank (p. 62). For further discussion, see End Note below.

[11] At Monash University an electronic balance was used, accurate to 0.001gm, to weigh Ag4cu filings. The minters at Croton must have used a reasonably accurate weight balance to achieve their low standard deviations in blank weight.

[12] During this 'spreadability' experiment, various furnace exit temperatures were tried. It was revealed that, if the alloy is poured at a temperature of 1100°C or higher (at least 50°C above the melting point), surface tension draws the pellet into a smaller, thicker spheroid shape before it solidifies, especially if the pellet weighs around 10gm (Graph 1, p. 31).

[13] We conducted further experiments to test if an 8gm solidified Ag4Cu pellet would spread radially when struck between dies. It does not. Nor does applying pressure to the pellet between flat plates produce a flattened disc. The blanks must be manufactured to the desired coin size by some other method prior to striking into coin. Yet another test showed that striking coins 'hot' cannot be carried out in practice; the blank loses heat so rapidly that, for metallurgical purposes, it is 'cold' by the time it reaches the dies after being removed from the furnace.

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solidified to allow removal of the cast blank. Each cavity in the joined mould was capable of holding 8gm of the molten Ag4Cu alloy. These cavities were each fed from a reservoir above through a narrow conduit. In practice, the reservoir above had to hold at least 16gm of molten metal to ensure that it flowed through the conduit to fully fill the 8gm mould below before the metal solidified.

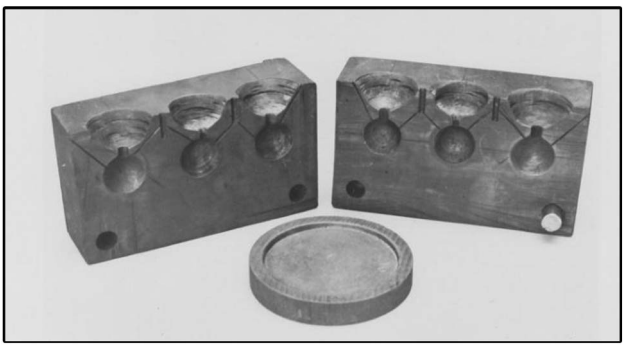


Fig. 8

Carbon split- moulds for making three pellets, and flat plate. Each reservoir in the mould above holds at least twice the amount of molten alloy than the pellet cavity below. The flat plate was used for the "spreadability" tests, which proved that 8gm of molten Ag4Cu poured onto it will not spread to more than c. 17mm.

We opted to melt 24gm of Ag4Cu alloy (8gm for the mould, plus c. 16gm for the reservoir above) for the experiment of pouring into these split-moulds, carrying out one melting operation at a time for each mould.[14]

This method, however, uses a large amount of heat energy. The solidified 16gm reservoir has to be cut from the pellet (Fig. 9) and returned to the forge later to be re-melted. In effect this means that each 8gm of Ag4Cu has to go through three melting processes before becoming a pellet. In addition, the forge has to melt c. 24gm of the Ag4Cu alloy in a container capable of pouring the liquid into the split-mould cavity and, furthermore,

[14] It seems unlikely that the Croton minters had the technology to create a forge capable of melting large enough quantities of this alloy and to keep it in a molten state in a crucible long enough to be able to pour it into more than one mould at a time. Ag4Cu alloy melts at 1050°C. (By comparison, pure iron melts at c.1530°C, pure gold at 1063°C, lead at c. 330°C, and tin bronze of the type used for bronze-work in ancient Greece c. 800°C, and 99% pure silver melts at 961°C. See http://garelicksteel.com/pdfs/melting_melting_points_of_common_metals.pdf). Reasonably large quantities of molten tin bronze at 800°C were required to produce the impressive bronze cast artwork of the 6th and 5th centuries: see Carol C. Mattusch, *Classical Bronzes: The Art and Craft of Greek and Roman Statuary* (Cornell University Press 1996) 10-16. However, these large, hollow bronze figures were cast in sections in a 'one-off' casting operation and assembled later as the final piece of artwork. It would require considerably more continuous heat output from a forge to melt – and keep molten – sufficient quantities of Ag4Cu (melting point 1050°C) long enough to pour the metal into numerous small moulds for continuous coin blank manufacture.

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the split-moulds (having a limited useful life) would have to have been regularly produced with great accuracy and consistency to produce pellets within the weight standard deviation of the Croton coinage.

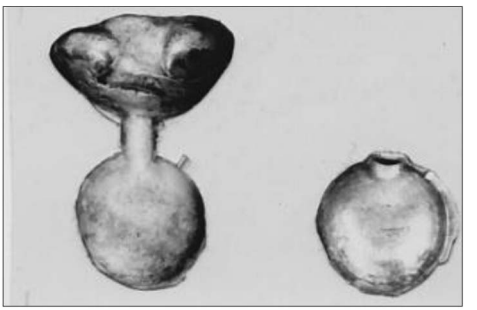


Fig. 9
16mm pellet with reservoir attached, and pellet with reservoir clipped, leaving remnant 'sprue' at the edge.

Despite these difficulties, however, it is possible that, in the production of a small series of late incuse coins, ancient minters used split-mould casting to make coin pellets. The existence of two incuse coins of Croton of 22mm diameter indicates the practice of split-mould casting. On the first coin (Fig. 10) there appears to be a remnant 'sprue' left when the reservoir metal was clipped from the pellet. On the second coin (Fig. 11) there is an 'equatorial ridge' that was cast into the pellet because of an ill-fitting split-mould.[15]



Fig. 10
Late 20mm Croton incuse with remnant 'sprue' at edge, indicative of the coin pellet being made in a mould.



Fig. 11
Late Croton incuse with remnant 'equatorial ridge', possibly struck from a pellet made from an ill-fitting split-mould.

[15] These two coins are from a late series of small tripod incuses (27 coins extant) from Terina, founded by Croton in c. 480 BC, containing the letters TE in the field. The series

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Pre-weighing alloy chips or filings before melting them proved to be, in practice, the best way to produce pellets of consistent weight with minimal heat loss, and would be a reliable method over long periods of coin production.

Producing the Best Shaped Pellet for Making the Blank Disc

An optimal shaped pellet (a 'flattened spheroid') was obtained by tipping 8gm of pre-weighed silver alloy filings into a small depression in a small carbon block[16] and placing it in the furnace, set at 1050 degrees Celsius, until molten. Almost immediately after the block was removed from the furnace the silver alloy solidified, since the small carbon block rapidly loses its heat and the small amount (8gm) of molten silver contains only a small amount of heat energy, which also rapidly dissipates.

The 8gm, 18mm, as-cast, Monash 'flattened spheroid' was sectioned, mounted in resin, etched, and photographed through a microscope. Fig. 12 shows the resultant as-cast microstructure (X 60) which is typical of this alloy. Crystals align in evenly spaced rows or layers.



Fig. 12
Cross-section of as-cast microstructure (X 60) of Ag4Cu alloy, in which crystals are evenly spaced and streamlined in layers.

Hammering the Pellet into a Disc

The spheroid pellet, with the flat upper surface, is a convenient shape to begin the light hammering process to produce a disc for minting.[17] As the alloy pellet is hammered and flattened, it begins to work-harden at the surface and, as it becomes thinner, it work-hardens right through its cross-section. When the disc has been work-hardened right through, it will crack at the edges if hammered further (Fig. 13). The spheroid shaped

has a standard deviation of 0.16. In our experiment we made 32 pellets from a split-mould, with standard deviation of 0.11. Hill (n. 2) 6 refers to the same phenomenon (using split-moulds to produce pellets) in some other coins of Magna Graecia.

16 For simple production methods used in making charcoal, see: L. Horn, 'Fuel for the Metalworker: The Role of Charcoal in Ancient Metallurgy', *Expedition* (Fall 1982) 9-11.

17 Placing the pellet with its flat upper surface face down on the anvil prevents the pellet moving laterally under hammering.

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pellet allows maximum deformation to take place in the middle of the disc before the outer areas become work-hardened and crack. A genuine incuse coin of Croton with a diameter of 24mm (Fig. 14) show cracks at the edges that were made during the manufacture of the blank.[18]

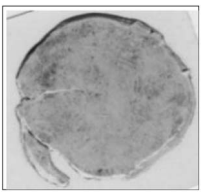


Fig. 13
An 8gm pellet hammered past 24mm and cracked. The tongue of metal has resulted from hammering out a flaw in the cast pellet.



Fig. 14
24mm 'Heron' coin (obverse) struck on a blank with cracks at the edge.

Graph 2 (p. 32) shows the relative hardness at the centre of the blank's cross-section after various percentage deformations. At 50% reduction in thickness, the 8gm disc is 2.1mm thick and the hardness has reached 115 HV.[19] The blank diameter is now approximately 22mm. At 60% reduction in thickness, the disc is 1.7mm thick, 24mm in diameter, and has a critical 118HV.

These figures are of crucial importance: it is at a diameter of 24mm, a hardness of 118HV, and a thickness less than 2.0mm that the 8gm disc can no longer be hammered without cracking. For an acceptable impression to be imparted by the dies onto a 24mm blank to make a coin, or to continue on and hammer the disc out to 30mm, the blank has to be softened by an annealing process.[20]

[18] A few other examples of edge-cracking on blanks are evident in the extant Croton coinage, but mostly the coin-makers were careful in determining the right time to stop hammering the blank. Often, however, coins show signs of having their edges nicked during circulation to test authenticity, particularly if the coin appears oversize or worn.

[19] HV is the abbreviation of the term 'Vickers Hardness', and refers to a standard measurement, based on the size of the imprint made by a standard pyramid-pointed tool when pressed into a metal sample by a standard force, in this case 5 kg. HV allows comparisons of hardness to be made between different metals (http://www.instron.com.au/wa/applications/test_types/hardness/ vickers.aspx).

[20] 'Annealing' is a heating process that softens metal by altering its microstructure.

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Fig. 15 shows the microstructure (X 60) of a disc that has been hammered, in this case, from an as-cast, 15mm blank to 17mm (20% deformation), with HV of 95 at the centre of the section. The disc has been reduced in thickness by almost 1mm – from 4.3mm to 3.4mm. The as-cast crystal streamlines have been flattened and distorted – they have been strained.

Fig. 16 shows the microstructure (X 220) of a disc that has been hardened by hammering the spheroidal pellet flat to 22mm diameter, annealed by

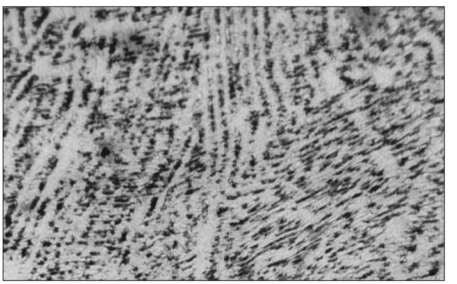


Fig. 15
Cross-section of the as-cast pellet (left half of image) and 20% reduced microstructure (right half) (X 60). Here the alloy crystals have been distorted under compression.



Fig. 16
Cross-section microstructure (X 220) of a 22mm Ag4Cu alloy Monash coin that has been work-hardened by flattening from a 17mm pellet, annealed and struck between dies. Large crystals in the centre show random growth when annealed. The growth crystals near the surface (top right) have been distorted by the die strike.

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holding the temperature at 500 degrees Celsius for 30 minutes, then struck between dies. The flattened (strained) crystals have grown randomly by the annealing process into large crystals across the entire section, releasing the strain. This crystal growth, after the metal has been work-hardened and then annealed, is normal for this alloy. The large crystals near the surface have been distorted by the dies when the blank was struck into a coin.

Comparison of Monash 'Coin' Microstructures with Genuine Incuse Microstructures[21]

Fig. 17 shows the crystal structure (X 120) of a genuine 19mm diameter Croton incuse. The microstructure is similar to that of the 22mm 'Monash' coin (Fig. 16). Large random crystal growth caused by annealing is evident across the section, and these large crystals were distorted near the surface when the blank was struck between dies.[22]

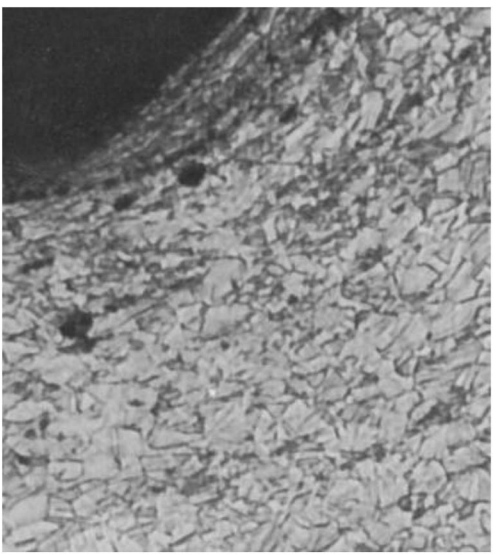


Fig. 17
Cross-section microstructure (X 120) of a 19mm incuse coin from Croton. The coin shows similar structures to Fig. 16. It was struck on a blank that had been annealed after being work-hardened (flattened). The large regrowth crystals are present in the structure; those near the surface (top left) have been distorted by the die strike.

[21] The most recent analysis of genuine incuse coins has been made by Kenneth Sheedy et al., 'Strange Objects and Strange Explanations: Understanding the Incuse Coinages of South Italy by Non-Destructive Neutron Diffraction and Tomography', Unpublished paper (2015).

[22] The same observations were made by Elam (n. 10) 60-3.

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This comparison means that the ancient coin makers were softening their 8gm, Ag4Cu, flattened discs even to make the 19mm coinage. They must also have softened their flattened disc to make their 22-24mm incuses.

The experiment continued by striking a softened 22mm diameter blank between dies, removing the coin from the dies, re-softening it and then re-striking the coin between the relocated dies.[23] This was done to examine further changes which occur to the crystal structure when a coin is worked after annealing – in this case worked by the second die-strike. Fig. 18 shows the changes in the microstructure (X 60) in the area where the die made the imprint in the first strike. When large, regrown crystals have been distorted and annealed again, they re-grow into smaller crystals. The image shows these small, re-growth crystals near the surface (where the first strike had distorted them) which were then distorted by the second die strike.

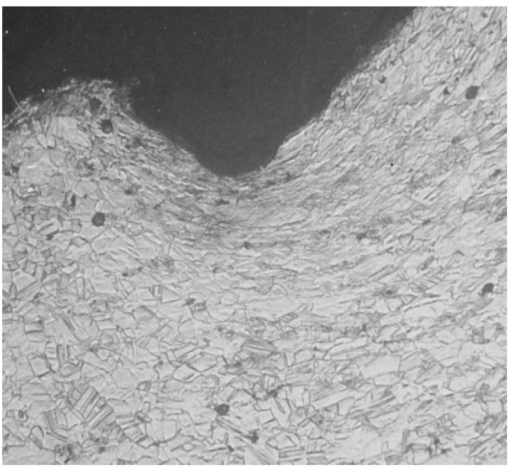


Fig. 18
Cross-section microstructure (X 60) of a 22mm Ag4Cu alloy Monash coin after the 17mm pellet had been flattened to 22mm, softened, struck between dies once, softened and struck again between relocated dies. Large growth crystals from the first annealing were compressed (distorted) near the surface by the dies, then regrew during the second softening into smaller (secondary) regrowth crystals. These smaller crystals near the surface have been compressed by the second die strike.

Producing the 30mm Incuses

Another softened 24mm diameter blank was hammered out to 30mm. At this diameter the section had been reduced in thickness by more than 70% from the as-cast condition, and was now 1.1mm thick.

[23] When re-striking a half-minted coin between dies the coin must be relocated exactly with the dies, and the obverse and reverse dies must relocate exactly with each other, or else a double image will appear on the coin after the strike.

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This 30mm blank had to be annealed to allow the dies to impart the image successfully onto the coin. Softening at 500°C for 30 minutes and then striking between the dies usually produced a good quality image. However, when striking a particular 31mm blank between our Monash dies, it was too hard to receive successfully the imprint of the dies, even with two separate strikes (Fig. 19). This half-struck 'coin' had to be softened again (500°C for 30 minutes) for the dies to impart their image successfully onto the blank with a third die strike. Further experiments at this point showed that a thin, 30mm diameter, incuse, softened blank cannot be minted successfully without defects if the dies are not aligned; the reverse image interferes with the obverse image where they intersect.[24]



Fig. 19
31mm Monash coin after first die strike. The border and the tripod feet have not been completed. Another softening process was required to allow a second aligned strike between the dies to produce a satisfactory coin.

Fig. 20 (next page) shows the crystal structure (X 60) of the Monash 'coin' after the cast pellet had been enlarged by hammering to 24mm (strained), softened, hammered again to 31mm (strained again), softened again and struck between dies. The annealing processes are evidenced by the growth of the crystals after each straining phase, and the final distortion of these regrown crystals upon striking between dies. Note that the initial, as-cast crystals, distorted when strained (first hammering to 24mm), grew into large, variable sized grains with the first softening process, and then were streamlined with the second hammering, only to grow again randomly as smaller crystals during the second annealing process, and then to be distorted near the surface upon striking between the dies.

[24] All the earliest 30mm incuses from Croton (Delphic tripod), Metapontum (ear of wheat), Sybaris (bull), and Caulonia (Apollo advancing right) were minted with the similar images on obverse and reverse carefully aligned. Later, when coin thickness increased, few dies were aligned.

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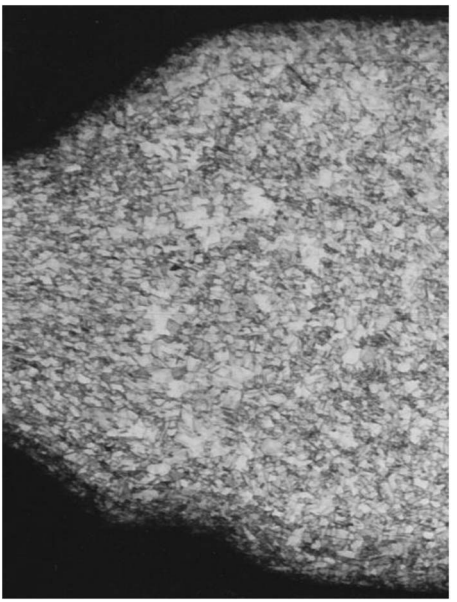


Fig. 20
Cross-section micro-structure (X 60) of a 31mm Monash coin made from a 17mm cast pellet which was hammered to 24mm, softened, hammered to 31mm, softened again, then struck between dies. The smaller, secondary regrowth crystals (appearing through the entire section after the second softening process), have been distorted by the dies near the surface.

The annealing process itself is heat-energy intensive. As well as having to melt the alloy in the furnace at the outset at 1050 degrees Celsius to create a 17mm pellet, an 8gm, 30mm diameter coin being minted on the production line at the mint at Croton would have spent at least two half-hour periods in the forge at 500°C to soften the blank, and may well have spent another half hour in the forge after the first die-strike – in a semi-completed state – to soften the coin in preparation for the second die-strike to complete the coin. On the other hand, 8gm of silver alloy melted at 1050°C, solidified into a pellet and hammered out to a 24mm diameter blank, would have only spent 30 minutes in the forge at 500°C – one softening process – to become soft enough to be successfully struck into a coin with a single die-strike.

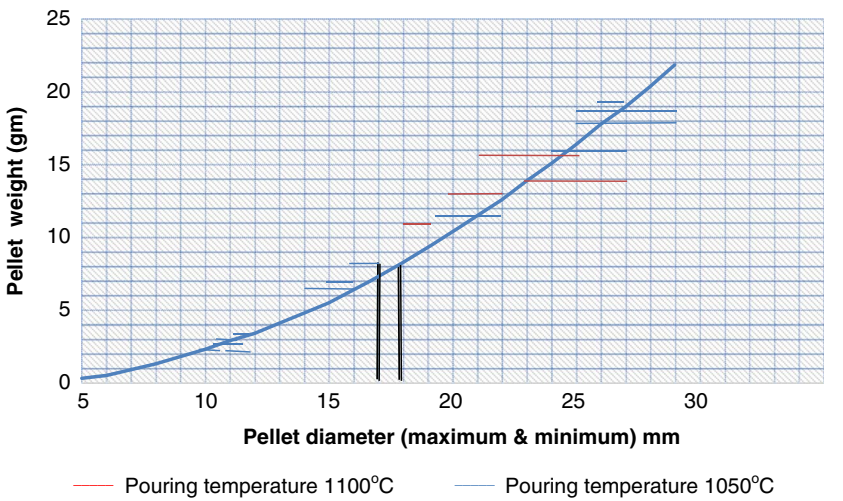
Conclusion

In light of the Monash experiments, it is possible to conclude that the Croton minters deliberately reduced the size of their coin blanks to take advantage of the shorter manufacturing process, allowing them to increase the rate of production of these smaller coins.

https://doi.org/10.1017/ann.2016.3 Published online by Cambridge University Press

The incuse coinage minted in the late 6th century by the four cities of southern Italy – Croton, Metapontum, Caulonia, and Sybaris – are closely related, right up to the destruction of Sybaris,[25] and the capture of its wealth by Croton in 511/10. After this victory it is plausible to assume that Croton's increase in wealth would call for an increase in coin production.[26] Reducing the blank size would allow the minters to meet this demand.

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Graph 1
Spreadability Graph (with line of best fit) shows that 8gm of molten Ag4Cu alloy at melting point 1050°C spreads to c.18mm when poured onto a flat carbon plate.

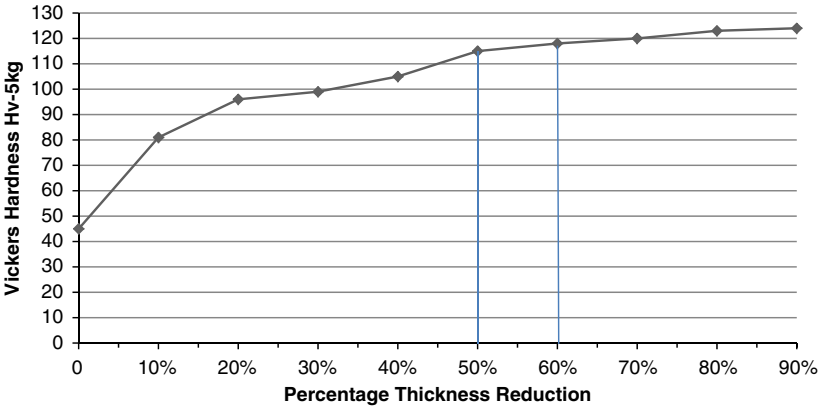
END-NOTE

C.F. Elam in 1931 (n. 10) made some interesting observations when examining the crystal structures of 15 silver Greek coins minted between 500 and 300 BC. Of great interest to us is her microstructure images of an 8.08gm, 28mm Sybaris incuse. From this evidence she concludes that the coin had

[25] Kraay, p. 170.

[26] For a discussion on the purpose and use of coinage in the late 6th century BC, see R.M. Cook, 'Speculation on the Origin of Coinage', *Historia* 7 (1953) 257-62.

https://doi.org/10.1017/ann.2016.3 Published online by Cambridge University Press



Graph 2

Hardness Graph shows that an 8gm 15mm Ag4Cu cast alloy pellet reaches c. 118HV after reducing its thickness by 60% through hammering. Cracking occurs when the thickness of an 8gm pellet is reduced to below 2.0mm and hardness increase to above c. 118HV.

been 'stamped direct from the casting. The shape of the original blank must have been round, thin, and approximately of the size of the finished coin' (p. 62). In the light of the Monash experiments, which show that 8gm, Ag4Cu alloy cannot be cast into a 28mm disc, Elam's conclusion requires some explanation. Fortunately this comes by way of discussion immediately following Elam's analyses. Dr S.W. Smith of the Royal Mint London explains that the Sybaris incuse microstructures (Elam's figures 10, 11, and 12) are very familiar 'because they represent fairly closely the microstructures of almost any modern coin over a wide range of silver composition. They indicate that the blanks had been cold-worked and annealed sufficiently to enable the coin to be struck, but not sufficiently to cause complete re-crystallisation. This procedure is characteristic of modern coining'(p. 68).

Without the image of the coin in Elam's report it is not possible to speculate further. But if, for example, the coin has a poorly struck image, it might indicate that the blank was not softened sufficiently – as evidenced by the microstructure's incomplete re-crystallisation – for the die to properly impart the image to the coin. Furthermore, Elam mentions that the rough edges of the coin are evidence that the coin had not been cold-worked.[27] On the contrary, however, it is the unworked, cast alloy that solidifies into a smooth-edged spheroid. The irregular edges on this coin are most probably the result of cold-working the blank. As noted above (pp. 24-5 and n. 18), edge cracks will occur when hammering the cast blank into a broader disc.

[27] Elam (n. 10) 62.

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