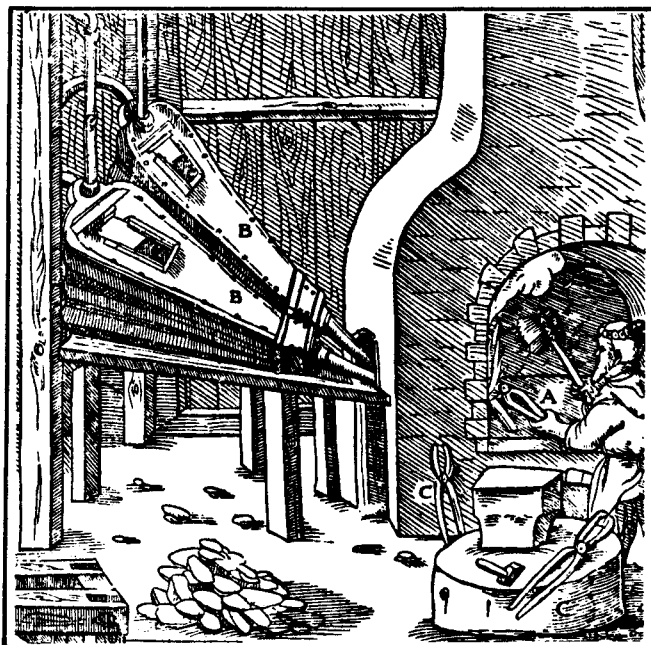
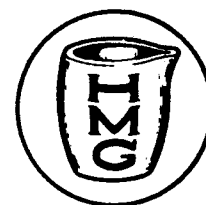


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Casting copper and bronze into stone moulds

by R F Tylecote

Two sets of stone moulds were made from York freestone – a fine grained but rather soft sandstone. The matrices were based on two Middle Bronze Age rapiers, a short one 38.5 cm long (A) and a longer one 45 cm long (B), both from the River Thames.

The stone-carving was done by a sculptor who worked with modern steel chisels and found no difficulty. There is no doubt that this operation could have been done equally well with bronze chisels. The dimensions of both the matrices were based on the rapiers themselves and this left no surplus metal for cleaning-up and working apart from the extra thickness that resulted from warping or bad-fit of the two half moulds. Set (A) had diagonal vents like the Knighton mould (*Fig 1*); the other had none.

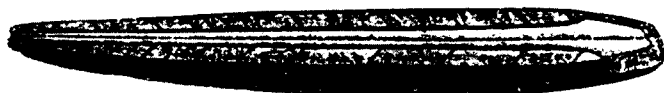


Figure 1 – One of the Knighton moulds after Evans¹

CASTING

First a small melt of cathode copper was made in a plumbago-clay crucible with a charcoal cover in a gas-air injection furnace. This was poured into an open stone mould for a small flat axe which had been heated to 200°C and dressed with lamp-black. As expected the casting gassed violently and was useless. But it did prove that lamp-black was a suitable dressing for a stone mould as no sticking was experienced.

The mould was redressed by brushing-on more lamp-black (*soot*). The “gassed” axe was returned to the crucible and remelted without the charcoal and with the addition of a small amount of copper oxide. This was cast as before with much better results. Some blow holes were present and more oxide would have been desirable. Obviously, it is better to ensure over-oxidation rather than the presence of hydrogen. This conclusion is in agreement with the structure of most copper artifacts. This result would correspond to the “sunk set” (*under-poled*) stage in copper refining and would result in an oxygen content exceeding 0.1%.

An 8% tin bronze was melted under charcoal in the same furnace; the charcoal was removed and more tin was added to make the tin content up to 13.6% – the mean value for the Middle Bronze Age. The two-part stone rapier mould (A) was dressed with soot and placed in an oven heated to 200°C. The two halves were clamped together, supported

vertically, and a runner-bush of surface-dried “green” moulding sand was placed on top so as to allow the metal to be poured into the small 3 mm diameter ingate connecting with the tip of the rapier.

The fit of the two halves of the mould was not perfect and daylight could be seen between them. Preventing this would have meant very high clamping pressures which was felt undesirable. Obviously a certain amount of warping had occurred during heating to 200°C. The edges of the parting line could have been sealed with clay but it was felt best to try casting without sealing. As it happened, very little metal entered the gap between the two half-moulds and a perfect fit was not needed. Nor may it have been all that desirable, as the gap allowed air to leave the mould cavity.

The casting (A1) appeared to be a good one apart from three cavities which could have meant its rejection under modern conditions. After cleaning-up, however, it was seen that there were a lot of small cold-shuts along the cutting edges and it would seem that it would be better to form the sharp edge by forging rather than direct casting. This may explain the signs of working seen on rapier blades. (*Fig 2A*).



Figure 2 – Experimental castings

- A (*top*) Rapier A1 after trimming
- B (*centre*) Rapier A2 showing holes near the top (*pouring*) end
- C (*bottom*) Rapier A5 as cast with shims, showing “flash” at edges which is later trimmed off

Two further attempts were made which were both relatively unsuccessful. (*Fig 2B*). The reasons perhaps were; (1) the two halves of the mould fitted too well – shims were to be inserted to prevent this in the next cast. Not only does a bad fit let the air out quickly but it effectively thickens the thinner sections of the mould and therefore facilitates running; (2) the pre-heat temperature was only about 100°C which is possibly too little. The runner-bush causes too great a heat loss if made of green-sand, particularly if the pouring stream comes into contact with it.

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HARDNESS AND MICROSTRUCTURE AFTER CASTING

- No. A1 - *Fine, cored structure with alpha-delta eutectoid. No slag - no cavities. Hardness 134 HV5. A good casting. (Fig 5).*
- No. A3 - *Much the same as above, perhaps slightly larger grain size but many cavities now as there was no feeding from the runner when the metal stopped running. Hardness 132 HV5. (Fig 6).*

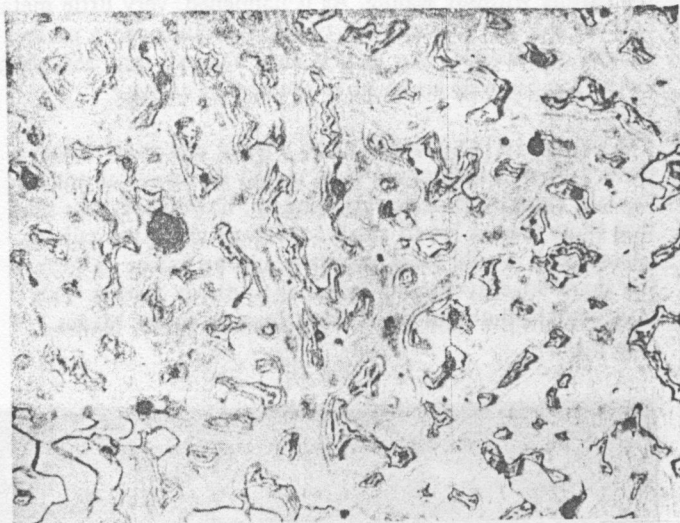


Figure 5 - Microstructure of A1 as cast X500
Fine, cored structure showing pools of alpha-delta eutectoid

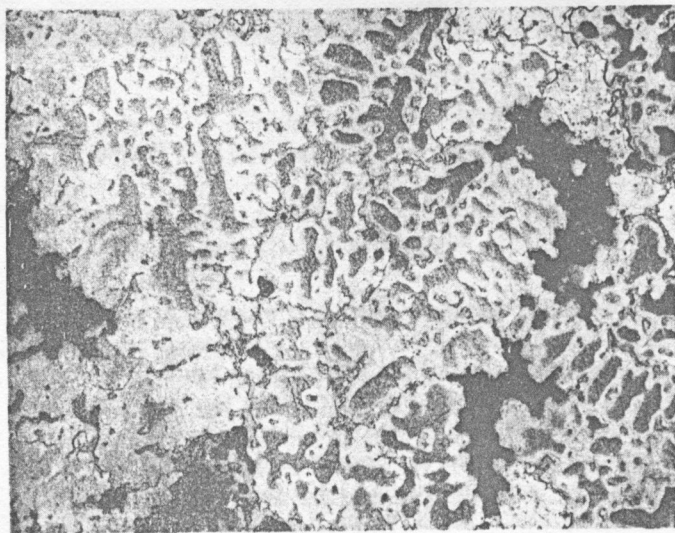


Figure 6 - Microstructure of A3 as cast X250
Showing shrinkage cavities

The second one of the two unsuccessful casts (No.A3) was short due to mis-running but, after fettling to give a blunt 1.5 mm thick edge, was used as a basis for forging experiments. In fact it was 25 cm long after fettling - a length well within the range of length of Irish dirks and rapiers. (Fig 3).

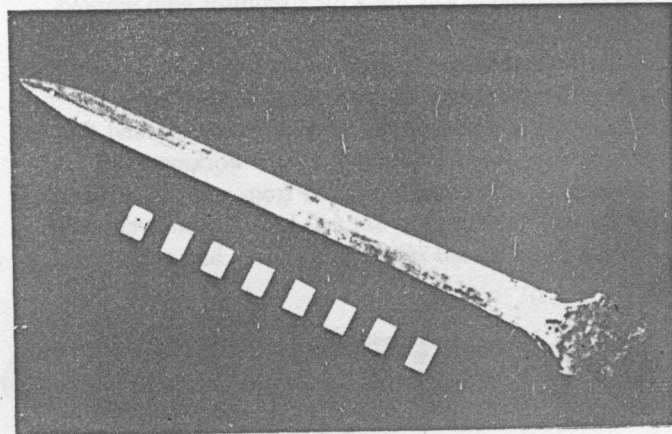


Figure 3 - Blade A3 after trimming and hammer hardening

After casting, the thickness of the two rapiers, A1 and A3, were checked with a micrometer along the spine as it appeared but they were not quite reproducing the contour of the mould. In fact the results made it clear that they were the same, apart from the fact that No. A3 (in which the two half moulds were clamped in the centre only) was slightly thicker than No. A1 where the clamping was at the two ends and not so tight. The maximum thicknesses were about the same as one of the Irish examples shown by Allen, Britton and Coghlan² (0.35 cm).

Two more castings were made in mould, A, preheated to 200°C. The first (No.A4) was made with the two halves clamped near the top. This was mis-run near the clamped region giving a rapier in two pieces, the bottom of which was usable after fettling. The second (No. A5) had steel shims 0.65 mm thick inserted between the two halves of the mould and the two halves were clamped midway between the two sets of shims. This arrangement proved very effective giving an extensive but uneven fin or "flash" all the way round and, of course, resulting in a blade thickened by 0.65 mm. The metal tended to run through the gap in two places and this may have been the reason for slight porosity near the clamped region. (Fig 2C).

It seems that air or gas tends to collect near the top of the mould where the section is thinner and that venting of the top is more important than the bottom. In a vertically cast mould the air can collect in the space above but must leave rapidly as the mould is filled.

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A second series with the mould sloping at an angle of 60° was made with mould B. The mould was preheated and supported in a gas-fired furnace and the preheat temperature was very high – about 300°C . A runner bush of pottery clay was moulded over the top of the two parts of the mould in order to permit satisfactory pouring through the top of the sloping mould. Shims were used as before and of course this mould had no vents cut into it. The mould had been allowed to dry for several weeks after assembly but, when pouring, the dried pottery clay spalled dangerously and it was obvious that this type of runner-bush was unsatisfactory.

A new type of runner-bush was made from a mixture of sand with about 20% of clay having a much higher permeability than the clay one. This was pre-moulded, dried and fitted to the top of the preheated stone mould with the aid of a metal sleeve (Fig 4). At first this was positioned in a sand bed at an angle of 60° without shims. The metal ran only about $2/3$ ds of the way down and failed to fill the butt. But it was clear that the running arrangements were now very satisfactory especially when care was taken to seal the joint between the metal sleeve and the stone with a clay lute. By this time the top of the mould was suffering from spalling and had to be trimmed and shortened so that the maximum length of the casting was only 43 cm instead of the original 45 cm for this mould.

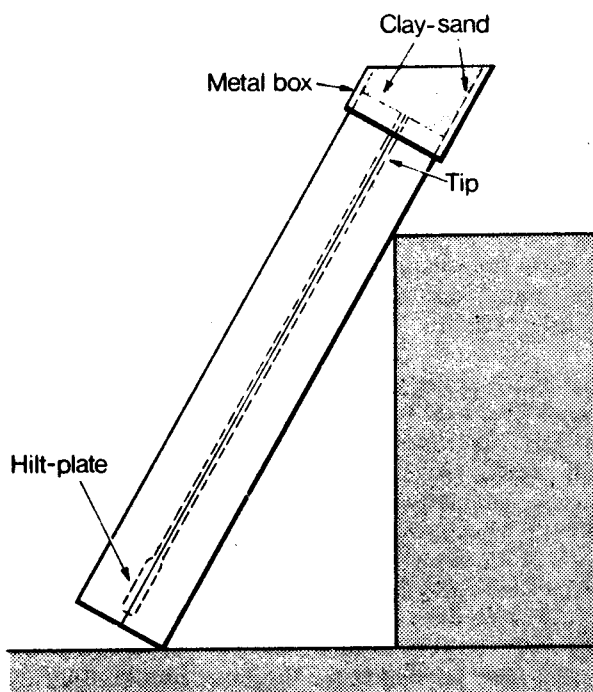


Figure 4

The next cast was made with 0.65 mm shims and the mould preheated to less than 150°C ; but the metal was well superheated and a very successful casting was made.

HAMMER HARDENING OF THE EDGES

After casting and trimming blade A3, it was homogenised by heating it in a charcoal hearth to make forging easier. This removed the coring of the cast structure and should have converted it to a more or less equiaxed structure with more of the tin in solid solution. Hammer hardening was carried out with light blows from a ball-peen hammer. But in order to prevent the blade running away from the hammer the opposite edge had to be supported with a stop in the manner shown in Fig 8. After working, annealing and reworking a section was removed from the edge near the tip of the blade (Fig 7). It was found to have a hardness of 224 HV2.5 and consisted of equiaxed and twinned grains with a high density of deformation markings. There was now no residual porosity and the yield point had been much increased by the cold working as shown by the blade's increased resistance to plastic deformation by bending.

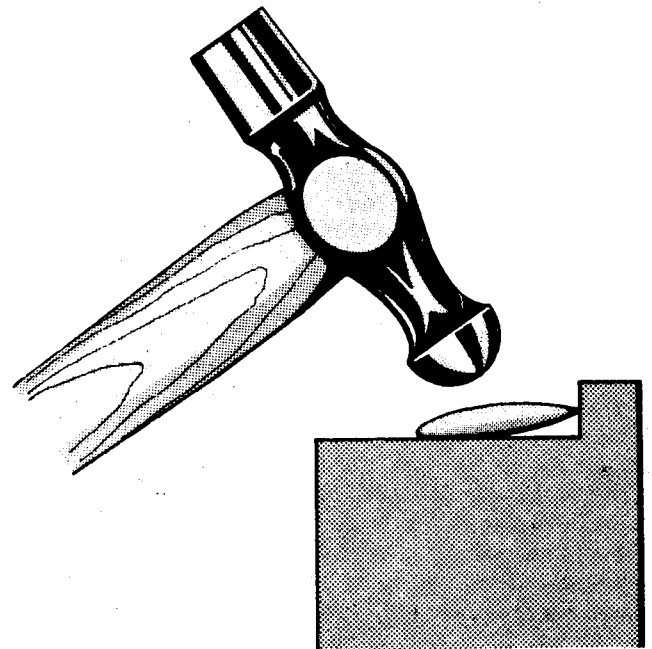


Figure 8

CONCLUSIONS

The problems were not those expected. There are no real metallurgical problems in casting this sort of tin-bronze; it has a low melting point and if the charcoal is removed from the surface at the right moment no gas should be present. Apart from spalling difficulties which were probably due to the use of only a moderately refractory stone, casting in

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stone moulds is a positive delight compared with sand casting once the problem of avoiding the static bubble that forms in the top of the casting is solved by the use of a sloping mould.

The main trouble is to get the maximum degree of venting with the minimum loss of metal. No doubt experience helped the early smiths and shims were added until the optimum situation had been obtained. Shims could have been made from clay, mica or slate.

By themselves the grooves cut into one of the two halves of mould A were insufficient and superfluous as the same effect could be got by the use of shims. It looks as though the vents cut into the Knighton mould were merely an experiment on the part of the smith unless the stone from which the Knighton mould is made is a great deal more permeable than that used in these experiments.

One must remember that the matrices used were based upon the actual artifacts themselves and that the moulds themselves might have been deeper, and the surplus metal resulting removed by fettling and hammering. The critical position seems to be 2/3rds of the way up the blade when the metal is poured from the tip, and one cannot help feeling that if the mould had been made to give a slight thickening in this region there would have been less difficulty in running. The surplus metal could have been forged away giving a slight lengthening of the blade. The thicknesses of the recorded rapiers shown in Table 2 suggest that our blades are on the thinner side of the range; it is noteworthy that our thicknesses are on the blades as cast while those of the rapiers in museum collections are blades that have been forged and polished. It would seem therefore that 0.38 cm is the thinnest blade that can be made from a straight tin bronze in a stone mould. This does not mean that such a thickness is the thinnest piece of metal that can be made, but is that that can be used as a runner to feed other parts of a casting such as the hilt-plate in the case of a rapier.

Not all moulds have been designed to be run from the tip of the blade; some have been filled from the hilt end but it would not seem that there is any advantage in this. The runner can be more easily removed from the tip, and either end works satisfactorily once the conditions are right.

One of the most striking conclusions from the metallurgical point of view was the high degree of homogenisation obtainable in what was a 13.6% tin bronze. This is the theoretical limit of solubility of tin in copper and the intention of the homogenisation treatment was to approach this figure, with little likelihood of actually attaining it. In fact no alpha-delta eutectoid is visible in the structure shown in Fig 7 and all the tin seems to have gone into solid solution. This fact clearly assisted the improved workability of the material

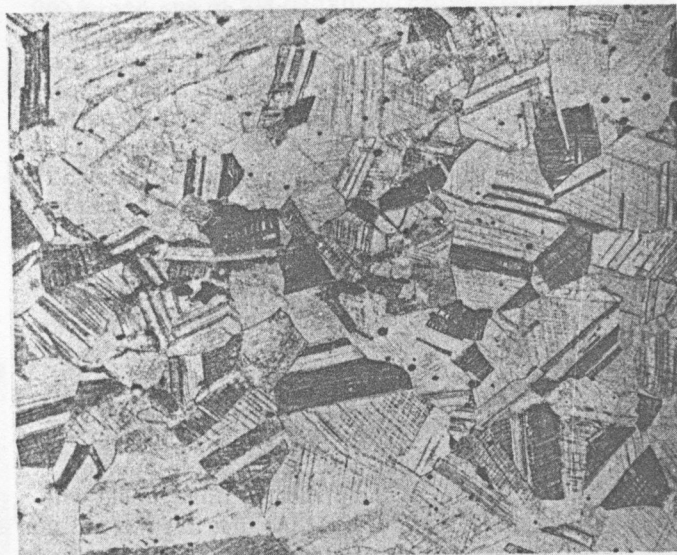


Figure 7 — Microstructure of blade A3 after homogenisation and hammer hardening X250

and enabled us to get the high hardness of 224 HV from the cold worked edges. This is much higher than the highest (164) yet recorded (Table 2). This aim has probably been assisted by some loss of tin in melting and it is probable that the actual tin present is no more than 12%.

Metal cast in stone moulds is completely unoxidized on the surface, unlike that in sand or open moulds, and needs no cleaning apart from fettling (*cleaning off the surplus metal "flash" at the edges*). There is no tendency for the metal to stick to the stone and it would seem that this is one of the least important problems of early casting. Dressing of the moulds was not necessary for every casting. Probably five or so could be made before resooting was necessary. Mould temperature is important, as it affects fluidity but the correct temperature can be ensured by building a small charcoal fire round the assembled mould. The degree of "shimming", and metal and mould temperatures, are all interdependent.

It is worth noting here that out of 1100 rapiers from the British Isles only two are in any sense identical. The reason for this is now clear from the results of this work. While it is possible that rapiers cast in the same mould may be reasonably alike after trimming it is unlikely that such a likeness would persist after cold hardening. But it would be unusual for two castings to be identical; if the smith had a badly run casting from a long mould, it is likely that he would settle for a short rapier rather than melt it down and recast it. This would be the main advantage to be gained from pouring at the tip rather than the butt. Next time he might be luckier and get a full length casting.

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TABLE 1
Experimental Results

Series	No.	Preheat °C	Results
I Vertical mould	A1	200	Good cast but cold shuts; length, 38 cm
	A2	100	Mis-run; holes near centre. length, 38 cm
	A3	100	Mis-run; reduced to 25cm and forged to harden edges
	A4	200	Mis-run
	A5	200	Shims added; good casting 38 cm long
II Inclined mould	B1	300	Clay runner; spalled
	B2	200	Clay-sand runner; mis-run
	B3	150	Shims added; good casting 42 cm long

TABLE 2
Comparison with early rapiers

Provenance	Length	Maximum Thickness cm	Maximum Hardness HV	Tin %
Thames, Battersea PR 1488	52.6	0.65	104	10.98
Ireland, PR 1884, 119, 268		0.58	150	13.93
Ireland, PR 1884, 119, 269		0.65	124	8.80
Ireland, PR 1884, 119, 270	25.3	0.35	144	6.2
Ireland, Wexford, PR 1884, 119, 271		0.52	75	6.63
Farnley, DN 239	—	—	124	12-15
Corbridge, N'land DN 238	34	—	164	10
A3 This report	25	0.46	224	13
A1 This report	38	0.43	—	13
B3 This report	42	0.38	—	—

ACKNOWLEDGEMENTS

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- 2 I M Allen, D Britton and H H Coghlan. *Metallurgical Reports on British and Irish Bronze Age Implements and Weapons in the Pitt Rivers Museum*. Occas. paper 10, Pitt Rivers Museum, Oxford, 1970.
- 3 C B Burgess (*with an Appendix by R F Tylecote*). *Bronze Age Metal Work in Northern England, c1000-700 BC*. Newcastle, 1968.

FIGURES

- 1 One of the Knighton moulds (*after Evans*¹).
- 2 Experimental castings –
 - A Rapier A1 after trimming.
 - B Rapier A2 showing holes about 2/3rds of the way up near the top (*pouring*) end.
 - C Rapier A5, as cast with shims showing “flash” at edges which is later trimmed off.
- 3 Blade A3 after trimming and hammer hardening.
- 4 Arrangement for casting with a sloping mould.
- 5 Microstructure of A1 as cast (X500). Fine, cored structure showing pools of alpha-delta eutectoid.
- 6 Microstructure of A3 as cast (X250). Cored structure showing shrinkage cavities.
- 7 Microstructure of blade A3 after homogenisation and hammer hardening. Equiaxed grains showing twinning and heavy deformation markings. (X250).
- 8 Arrangement used for hammer hardening.