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RESEARCH ARTICLE

The Gotlandic box brooch from Fyrkat grave IV. A research into the casting technique and work methods associated with multi-piece brooches

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ABSTRACT
This study of the box-shaped brooch uses experimental archaeology in an attempt to gain more information about how these combination brooches were made. Some misunderstandings are addressed concerning the Fyrkat box brooch and Viking Age bronze casting in general. When trying to recreate the brooch, the four knot-shaped animals cast as one with the brooch throughout the work turned out to be the common denominator. They forced the original artisan to sacrifice an elaborate wax model when making the clay mould. Hollow models made of metal or solid bone could be used to produce this brooch only with difficulty. Again, due to the figural ornaments, a very complicated and time-consuming silver-plating technique was called for. Simple pure silver encasing was rendered nearly impossible. The very complex techniques used appear to have been the trademark of the artisan, designed to demonstrate his skill.

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Introduction

The exhibition *The Vikings* in 2013 in Copenhagen brought renewed attention to the Fyrkat ring fortress near Hobro in Jutland. The predominant focus was on one of the graves at the Fyrkat graveyard – the inhumation grave IV, often referred to as 'the grave of the seeress' (Pentz and Prince 2013, pp. 196–197). Another designation for a seeress known from the Nordic sagas is *völva* (Pentz *et al.* 2009). Over time a particular item among the many exotic goods from grave IV has come to represent the Fyrkat seeress – a box-shaped brooch from the island of Gotland (Figure 1).

Grave IV dates to the period when the Fyrkat ring fortress had a purely military function, namely from the end of the 70s and into the 90s of the 10th century AD (Roesdahl *et al.* 2014, pp. 254–55).

This paper concentrates on the study of the box brooch and uses experimental archaeology to try to identify at least some of the techniques used to create the original brooch. The box brooch from Fyrkat would appear to represent one of the more advanced bronze brooches from this period. Indeed, these gold and silver-adorned brooches are categorized by the leading expert in the field, Lena Thunmark-Nylén, as 'praktspänner/brooches of splendour' (Thunmark-Nylén 1983b, p. 125.). The question is, were all the techniques associated with the manufacture of box-shaped brooches really that complicated, or just more time consuming? In order to find factual and objective answers, it is necessary to try to recreate the Fyrkat brooch.

Experiments based on the study of prehistoric metal brooches tend to involve five stages. The first stage, after a thorough study of the original material, consists of making a new model for the brooch in question. Using a rubber mould copy or a 3D scan copy is out of the question, in order to be able to address the question of what material/materials could have been used for the model. The second stage is making the mould for the casting. What materials for moulds were at the artisan's disposal in a prehistoric context? What do the archaeological finds tell us? Stage three is the casting itself: metallurgy, technology, heat resources, etc. Stage four encompasses the cold work of the raw casting: in short, any work – including repairs – done to the raw casting. Stage five normally involves the collaboration of other experimental archaeologists and colleagues. For example, in collaboration with textile experts, replica brooches with the proper needles can be tried on reconstructed costumes. In this paper,

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The following article is dedicated to the memory of Bjarne Lønborg (1949–2016).

Figure 1. D 169–1966. Fyrkat grave IV. Box-shaped brooch fason Gbl. 4/type 7b.

the author will mainly concentrate on stage two and part of stage four.

Experimental archaeology is still a relatively recent research method within professional archaeology. In Britain, John Coles with his eightfold principles defined experimental archaeology in 1973: '(1) All materials used should be those locally available to the society under study. (2) All the methods used in experimentation should remain within the bounds of the possible. (3) Modern technology should not interfere with the experiment, but should only be used in the analysis of results. (4) Both the scope and appropriate scale of work should be properly assessed in advance, but also in the light of the experiment itself (i.e. one should always factor in the sourcing, collection and transport of the materials used, as well as the time and manpower entailed). (5) Archaeological experiments should be repeatable. (6) A desired end result should be considered at the outset of each experiment. (7) The results should consist of observations that lead to suggested conclusions (in other words, the fact that something was possible does not necessarily mean that it was done that way). (8) Every experiment should be honestly assessed and the errors openly stated' (Coles 1973, p. 15ff.).

There is of course also a never-ending, self-teaching curve in conducting bronze-casting experiments with Viking Age techniques. Many prehistoric items were produced using techniques that are now at least partly forgotten. The author of this paper has conducted some 1500 copper-alloy castings using prehistoric methods since graduating in 1992 as an archaeologist at the University of Copenhagen. Most of the work has focused on Scandinavian brooches from the late Iron Age and the Viking Age (Hedegaard 1994, 2005, 2010b).

Typology and chronology

The brooch from grave IV is a Type 7b after Lena Thunmark-Nyléns' 2006 typological revision of Gotlandic box brooches (Thunmark-Nylén 2006, pp. 76–7). In Thunmark-Nyléns' earlier and meticulous work from 1983, the Fyrkat brooch was classified as a fason Gbl 4. Gbl stands for Guldbleck/Goldfoilmetal (Thunmark-Nylén 1983b, p. 25). In the present paper, it has been considered more practical to use mainly the 1983 typology as in this earlier work Thunmark-Nylén tried to identify the different prehistoric workshops for box-shaped brooches (Thunmark-Nylén 1983b, p. 8). The 2006 Type 7b also encompasses types of box brooches that in the 1983 work were defined as fason Gbl 5 and 6. At least from a metalworker's point of view, fason Gbl 5 and 6 stand well apart from the fason Gbl 4 (Thunmark-Nylén 1983b, pp. 76–9).

The production of Gbl 4 brooches seems to have begun in the first half of the 10th century AD. Worn-out fason Gbl 4/Type 7b brooches are known from graves on Gotland dating to the early 11th century AD (Thunmark-Nylén 2006, pp. 86–7). Therefore nearly identical brooches would have been in use on Gotland contemporary with the seeress at Fyrkat being in possession of her box brooch.

There is no doubt about the provenance of the Fyrkat box brooch. Gotlandic Viking Age brooches worn by women are very distinctive. Whereas in Scandinavia tortoise brooches worn in pairs were the dominant type, 'animal head-shaped brooches', also worn in pairs, were the fashion in Gotland (Carlsson 1983) (Figure 7). As a third brooch – often to hold a cape or a shawl, trefoil or equal-armed brooches were in favour in Denmark, Norway and Sweden. These were sometimes substituted by a trophy brooch (Hedegaard 2010a, pp. 71–4). The third main brooch on Gotland was the box-shaped brooch. Another possibility is the large, elegant, up to 16 cm long, disc-on-bow brooch (Thunmark-Nylén 2006, p. 51ff) or the more humble extra animal head-shaped brooch.

Box-shaped brooch fason Gbl 4 Fyrkat, grave IV D 169–1966

The Fyrkat box-shaped brooch is indeed a combination brooch. Originally, it consisted of 43 parts in total: eight parts cast separately in copper-alloy, two pieces of copper-alloy wire, a twisted silver wire, four gold foil pieces probably with gold granulation work, some 23 pieces of thin silver foil with niello inlay and five iron wedges. Most Viking Age 'standard' brooches made do with three parts: shell/bow, needle and pin for needle.

Today, the heavily corroded Fyrkat Gbl 4 brooch retains only two of its original cast copper-alloy parts, one iron wedge, a tiny fragment of one of the copper alloy wires and less than half of the thin silver foils. Luckily, one of the preserved cast parts is the main part; often referred to as the shell, the hull or the *drum*. One of the four original corner posts is still in place on the drum, secured by its iron wedge. The missing parts are presumed lost or removed, before the brooch came to rest in grave IV close to the head of the deceased.

The drum is, without the four-legged animal figurines on the top, 3.1 cm high, has a lower diameter of 6.0 cm and is 5.8 cm in diameter just below the top. The knot-shaped animals with their defiant stance add another 1.2 cm to the height of the drum. The four animals and the drum are cast as one and should therefore be seen as *one* single copper-alloy part. Other box brooches, like fason 5 and 6, have four separately cast animals on the top of the drum, which were riveted on (Figure 2).

The brooch found in the 'seeress' grave seems to have been transformed into a small cup. Bereft of its bottom plate and central boss attachment, the brooch in an upside-down position resembles a small, four-legged cup. However, some 20 perforations would have made the improvised cup somewhat leaky. To solve this problem the holes were filled by partly melting in some lead and partly by hammering in small lead plugs (Figure 3). The creator of the 'cup' could also have made use of beeswax or pitch for this purpose, but then the cup would not then have been able to hold a hot liquid. The lead is today partly corroded into lead carbonate. This last ingredient has given rise to speculation as to whether the seeress incorporated the lead in the form of a lead-white cream to give her face a somewhat paler complexion (Pentz *et al.* 2009, p. 220). This misinterpretation might have arisen from the typological term, box-shaped brooch. The designation *box* quite naturally makes many people think of a container, and the purpose of a container is to hold something. Indeed, a few box brooches and animal head-shaped brooches were used as makeshift piggy banks, holding a piece of amber, a few coins or maybe a small silver rod

Figure 2. Gbl. 4 box brooch with cast-in-one figurines and G 6 box brooch with riveted flat figurines. Replicas.

Figure 3. D 169–1966. Inside of drum. Notice lead plugs.

(Thunmark-Nylén 2006, p. 22). However, for the duration of the (approx.) three centuries that box-shaped brooches were produced, the bronze casters never seem to have felt inclined to change the brooch design towards genuine practical portable containers.

The Fyrkat box brooch has four ribbon-ornamented squares on its rounded octagonal sides, sitting between the open spacing for the attaching of the four corner posts (Figure 4). The ornaments are cast as one with the drum and have been fire-gilded with an amalgam of gold. Some of the ribbons in the ornaments have been cold-worked with a bead punch. In order to fasten the bottom plate, a protruding rivet was placed behind each ornamented square. One of the ornamented sides shows damage and a small part of it is missing, together with the rivet. If this damage did not occur during the excavation in 1954, then one gets the impression of a person either not caring or unskilled with metal-work. This person has tried to remove the bottom plate rather forcefully with hammer and chisel, thereby with a bold stroke removing not only the bottom plate, but also the entire rivet and part of the ornamented square.

Figure 4. D 169–1966. Corner post and ornamented square.

Some previous studies of Gotlandic brooches

Finds of typical Gotlandic brooches outside the island are relatively rare. The Fyrkat box brooch long remained Gotland's only representative in Denmark. The last four decades of metal detector finds have somewhat changed this. It started with a fragment of a 9th century AD disc-on-bow brooch at Humlebakken near Aalborg, and more has followed (Petersen 1991, pp. 57–60, Figure 9a).

In Hedeby in Southern Schleswig (Germany) two box-shaped brooches have surfaced (Hedegaard 1994, p. 312). One of these is the top shell for a double-shelled fason G2 (Hb. G8/2) and the other the small and uncomplicated fason BS4 (Kat.nr. 95). The later had been transformed into a weight by sawing off the needle attachment and filling the drum with lead.

Odense Bys Museer on Funen possesses in their comparative collection two box brooches, fason G 6 and P 4 (Figures 5–6) and two animal head-shaped brooches, types 4:5 and 5:2 (Hedegaard 1994, p. 312). How these unprovenanced brooches some hundred years ago ended up in Odense is today a conundrum.

The Hedeby and Odense brooches formed the initial Gotlandic research material for the author and the basis for the first experiments (Hedegaard 1994). The early research was facilitated by Anders Carlssons' 1983 work, 'Djurhuvudformiga Spännen', and Lena Thunmark-Nyléns' publication from the same year, 'Vikingatida Dosspännen'. For these two scholars, the manufacturing process of the brooches and the organization of the production is a natural and important element in their studies.

In 2000 the author, together with Dipl. Engineer Jens Fich at the C.C. Jensen Ship Window and Metals Castings Company in Svendborg, conducted a computer-simulated casting of a 11th century AD fason P 4 box brooch (Hedegaard 2000). The results indicated some 'problem zones'. Where a relative massive inlet for the metal meets the (approx.)

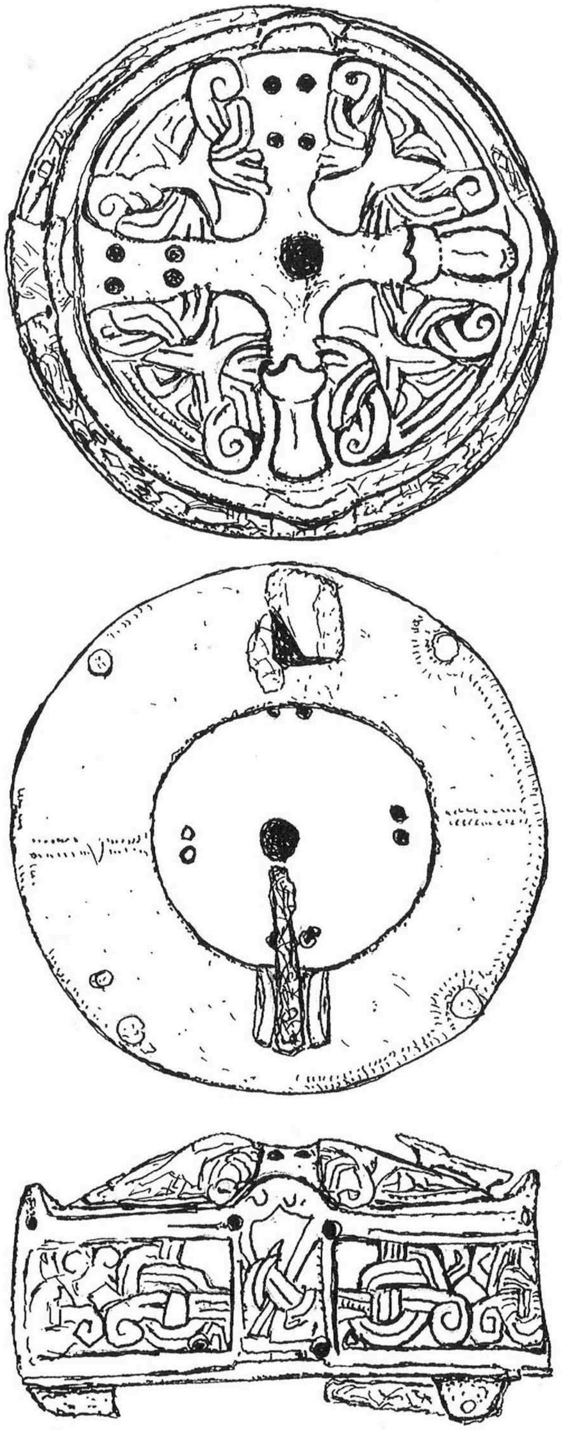

Figure 5. OBM 3200x29. Fason G6. Separately cast animal figurines and central boss. Lower diameter 6 cm.

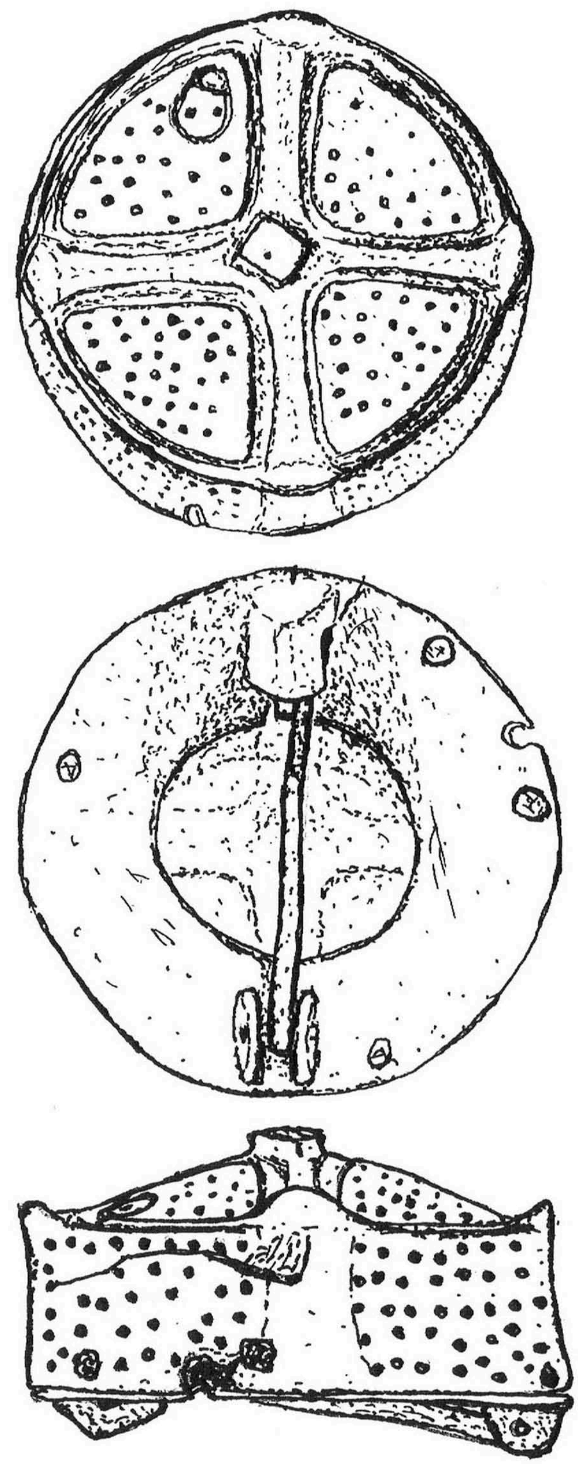

Figure 6. OBM 3200x27. Fason P4. Lower diameter 4.8 cm.

2 mm-thick wall of the brooch, there is a zone with a high risk for metal suction. This can result in a hole in the brooch after removal of the inlet. The animal head-shaped brooch from Funen (inventory number: OBM 3200x32) type 4:5 has such a casting error on its 'nose', thus proving where at least some of the Gotlandic metal-casters placed the inlet for animal head-shaped brooches (Hedegaard 2000, p. 83). Even more interesting, the simulation indicated a risk for the metal running cold at the

central boss on the top of the drum (Hedegaard 2000, p. 84). In the simulation, the sprue was placed at the lower rim of the drum. This position is borrowed, from what we know about the position of metal inlets in clay moulds for tortoise brooches (Brinch Madsen 1984: 33ff.). The fason P 4 brooch belongs to the group of relatively small box brooches – a fason P 4 is typically some 20–25% smaller than most fason G 6 box brooches. Comparing the amount of metal needed for casting a P 4 brooch to a G 6 box brooch, the latter will in general call for some 40% more metal than the former. The casting simulation programme predicted that the bigger the brooch, the greater the risk for a casting error involving the central boss. Fason G 3–6 all belong to a group of relatively wide and tall box brooches. When the casters on Gotland engaged in efforts to enlarge the size of the box brooches and wanted to secure an intact *and* enlarged central boss, they would have been well advised to go for separately cast central bosses. A fason P 4 brooch has in general a central boss cast as one with the drum (Figure 6), whereas a typical G 6 has a separately cast central boss (Figures 2 and 5). So changing a brooch design from nearly all details cast as one to a multi-piece brooch is not necessarily simply a question of fashion – it can be due to sound technologically thinking.

In 2009 the find of an animal head-shaped brooch type 4:5 in a grave with two tortoise brooches, type JP 37, generated renewed interest in Denmark for Gotlandic material (Figure 7). The grave in question is Snubbekorsgård grav 88 on Zealand (Sparrevohn 2009). Consequently, the author of this paper carried out new experiments with animal head-shaped brooches, this time focusing on metal models and three-piece clay moulds (Figure 8). This was inspired by A. Carlsson's identification of a hollow metal model for an animal head-shaped brooch (Carlsson 1983, pp. 79–80). A hybrid model combining a metal model and a bottom-plate in wax for a type 3:3 animal head-shaped brooch turned out to be very convincing. Not all box or animal head-shaped brooches with a fixed cast-as-one bottom plate call for a complete wax model that later will have to be sacrificed. However, the work method calls for clay moulds with a divided upper mould in order to liberate the hollow metal model.

Figure 7. Snubbekorsgård grave 88x20. Zealand. Animal head-shaped brooch type 4:5. Foto L. Sparrevohn.

Figure 8. Three-piece mould for type 3:3 brooch after casting. Bottom plate cast-as-one with brooch. Replicas.

The 2015 experiments

The above-mentioned renewed attention given to the seeress grave led to a demand at Vikingecenter Fyrkat for a fason Gbl 4 dissemination replica. The author of this paper was commissioned to undertake this project.

A replica of the drum was moulded in coloured wax. Wood – but especially bone – is suitable as material for a solid model for a box-shaped brooch, but wax is quicker to work with and errors can easily be fixed. Leather worked well in an attempt to recreate one of the four ornamented squares on the drum (Hedegaard 2005, p. 8; 2010b p. 95, Figure 15). To reconstruct a corner post for the Fyrkat brooch, wax seemed like if not the only, then the right, choice. Two wax plates were ornamented: one perforated plate with the posts' protruding ornaments and another plate with the deep-set ornaments. The first plate was placed on top of the second. The work was surprisingly easy. Once new mother models had been made by hand, these were copied using modern rubbermoulds.

At one point due to lack of time and skills, the work differed from the original brooch. The mainly 'steep rope cord'-ornamented silver-plated bands for the drum were substituted with a simple entwined wavy kordel ornamentation borrowed from a fason Gbl 5 box brooch (Thunmark-Nylén 2006 p. 78, Figure 53; SHM 12151). The kordel ornamentation was cast as one with the drum, as is also the case with many original brooches, but *not* with the Fyrkat brooch. Nevertheless, one wax drum copy was given bare, smooth bands. This version resembles the unfinished fason Gbl 3 box brooch from the Smiss find (Zachrisson 1962 p. 209, Figure 5). Gbl 3 and 4 brooches differ only in the ornaments on the squares.

The four knot-shaped animals for the top of the drum were also made in wax. They turned out to be somewhat difficult, and the animals ended up being too big. This mistake made the top of the drum a bit crowded.

The first three replica drums plus corner posts were cast in silicium-bronze, here referred to as 'CuSi bronze' (Cu 94%, Si 4%, Mn 1%, Fe 1%), a very hard alloy. The mould material was modern shell-casting (1).

The initial castings gave two extra box brooch drums: one with cast korde ornaments was intended for experiments with 'pure silver encasing' work and a second brooch with smooth bands for silver foil soldering work. New wax models for drums with more refined knot-shaped animals were now made. The intension was to form genuine clay moulds over these wax drums. The very plastic shape of the drums calls for moulds made in clay and excludes rigid moulds made out of, for example, limestone or solid bronze. The experiments took place mainly in the smithy at Vikingecenter Fyrkat. The work process

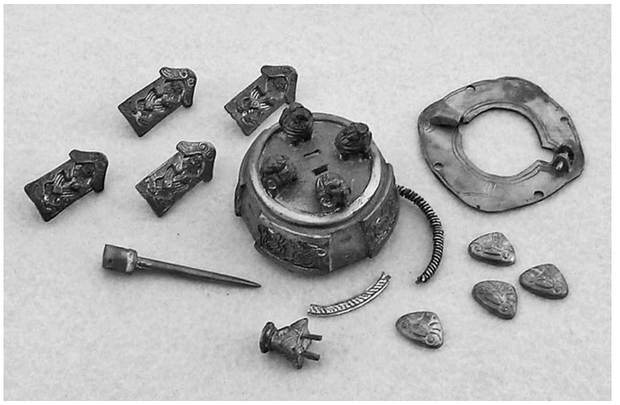

Figure 9. Fason Gbl. 4. Eight copper-alloy parts and more. Replicas.

was open to colleagues, students and the audience in general. An exhibition focusing on Viking Age Scandinavian and Gotlandic bronze casting supplemented the work. For the exhibition, the missing parts for the Fyrkat box brooch had been produced in CuSi bronze: bottom plate, cast needle, the three lost corner posts and the central boss. These parts were sourced from more intact fason Gbl 4 box brooches, like the one from Hellvi, grave 222c, C9322 (Thunmark-Nylén 1983b, p. 76, Figure 52a). This was to give the audience an idea about how many metal parts constitute a complete fason Gbl 4 box brooch (Figure 9). A positive bronze die had also been moulded in wax and cast in CuSi bronze. This was done in order to manufacture the four missing gold foils for the top of the drum. However, the foil that was actually put to use was cheap 0.4 mm copper.

Metal

It is brass alloys that dominate the more advanced box brooches, and it is important that the alloy contains as little lead as possible. This is due to the gold amalgam work, which is especially observed on Gbl box brooches. The mixture of mercury and gold used for amalgamating copper-alloy items does not adhere well if the content of lead exceeds some 2–3%. The casters on Gotland were very much aware of this fact, as we can see from well-preserved box brooches that have been metal analysed (2). The alloy selected in the experiments was 76.5% copper, 18.5% zinc and 5% tin. The fuel for melting the metal in a stone-lined pit was high-quality hardwood charcoal. The necessary 1200°C were reached with the help of manually operated double bellows. The chosen brass-alloy will be liquid at some 160 degrees below 1200°C, but excess heat is needed for the casting moment.

Crucibles

The crucibles we know from the Viking Age site Fröjel on Gotland seem to be dominated by a cylindrical design with a rounded bottom (Gustafsson and Söderberg 2007, p. 100, Figure 2). The shape of the Fröjel crucibles can be compared to the Ribe type 1 crucibles (Brinch Madsen 1984, p. 26ff.). In the Fyrkat smithy, crucibles of the semi-closed Ribe type 2 were favoured, in order to reduce loss of zinc during meltdown (Jouttijärvi 1999, pp. 44–5). These crucibles differ from Fröjel/type 1 by having a smaller top diameter. Ribe type 2 crucibles are thus in general more egg shaped than cylindrical. In addition, Ribe type 2 crucibles have a tap on the side. This tap has more than one function (Hedegaard 2005, p. 11). The 'hotspot' in a typical melting pit is between the blowhole and crucible. Placing the crucible with the tap pointing towards the blowhole in the melting pit, the tap helps to disperse the heat around the crucible. The tap, to a surprisingly large extent, also prevents the crucible from tumbling in towards the blowhole. A Ribe type 1 or type 2 clay crucible needs handling with iron tongs that have long, delicate, almost pincer-like thin arms. Unless the crucible is tiny and it and its content thus very light, you *never* grab a type 2 crucible at the very tap, but round the belly below or above the tap. Clay crucibles can at 1200°C be malleable, like marzipan. Many museum exhibitions and drawings in publications depict clumsy, unsuitable, heavy-duty blacksmith tongs for handling Viking Age clay crucibles.

A typical Viking Age type 1 crucible has a volume of some 20 cm^3 (Pedersen 2010, p. 173) and will thus in the author's experience hold on an average 120–180 g of copper-alloy in ingot and scrap form. Such a small amount of molten metal gives the bronze-caster only five to eight seconds to perform the casting, counting from the second the crucible is lifted free of the melting pit.

The CuSi-bronze replica drums, which already were at available, have a metal wall thickness of some 1.5–2.0 mm and their weight ranges from 126 to 156 g. Adding some 20 g for sprue and gate plus another 20 g for waste, it became clear that for the experiments we needed clay crucibles with a capacity of some 180–200 g of brass in ingot form. The crucibles were based on Miocene micaceous clay taken from the Gram clay pit in Southern Jutland (3). This very homogeneous clay was mixed with 30% ground, discarded crucibles, 20–25% fresh horse manure and a small amount of cut horsehair. The proportions for the mixture are in volume, not in weight. Crucibles made from this particular mixture normally stay servable for two and up to six 1200°C meltdowns. If the quality of the charcoal is compromised, a crucible might only manage one single casting.

It only takes some five minutes to form a type 1 or 2 crucible with your hands (Hedegaard 2005, pp. 10–11). After some three to four days of drying, the crucibles are pre-fired by placing them close to a fireplace. About an hour later, they are moved into the very centre of the hearth and are fired for a further three to four hours at c. 700°C.

Moulds

The clay used for moulds also came from the Gram clay pit. Clay from clay pits on Gotland ought to have been tested for both the moulds and the crucibles. However, the author did not succeed in obtaining such clay. The clay was dried and pulverized, whereby one can easily remove any impurities. The proportions of the mixture in volume are 50% fresh horse manure from grazing animals, 40% pulverized clay and 10% pulverized discarded moulds as temper. At this stage is also added cut horse or human hair. This last ingredient is difficult to measure; one should always go for a 'very hairy mixture'. If the horse manure is particularly fresh, only a small amount of water needs to be added in order to knead the mixture. This batch is referred to as '*regular mould-loam*'. A batch about the size of a loaf of bread is more than enough to make moulds for one fason 4 box-formed brooch.

A fistful of regular mould loam is now mixed with a fistful of pure pulverized clay that has been moisturized. The proportions for this new mixture will be some 70% clay, 25% manure and 5% temper. If deemed necessary, a little more temper is added. This mixture is referred to as '*impression loam*'.

A final mix consists of 95% pulverized clay and 5% pulverized discarded moulds, plus water. This mix is called '*the finer impression loam*' or simply the slurry. Only a small cupful is required.

For the past 25 years the author has based nearly all his Viking Age experimental castings on the above recipe for mould loam. However, the clay did not always come from Gram. Cow manure has also been tested and the resulting moulds were found to be very much in congruity with original Viking Age moulds (4).

It stands to reason that every Viking Age bronze caster would have had his own recipe for both crucibles and clay moulds. Natural clay has, depending on its chemical composition and levels of natural admixtures, very different physical properties. This will have an influence on, for example, the amount of shrinkage and the firing temperature. The artisan would have been strongly influenced by special local resources, like maybe a pit of prime quartz sand for temper in crucibles or butter clay from a nearby marsh for impression loam. Nevertheless, his mixtures for mould loam would have needed a content of at least 25% organic material. A common observation for Viking Age clay moulds is that they are light and porous. The Scandinavian late Iron Age clay mould technology is based on this porosity. Regular inserted air vents are not needed to help air and gas, mainly in the form of hydrogen and carbon monoxide, to escape from the mould cavity. It is important to understand that the gases rarely pass all the way through the mould – they are *absorbed* by the porous walls of the hot mould. Some gas and air will naturally also be able to escape along the junctions of a multi-piece mould. This casting technique must never be mistaken for the more modern flask-supported sand-casting.

The making of the moulds could now begin. As mentioned above, the four knot-shaped animals were cast as one with the drum on the Fyrkat grave IV specimen. This fact makes it very difficult, if not downright impossible, to use a solid model in a clay mould. Of course, it also makes it somewhat difficult for another less skilled or lazier bronze caster to copy 'our' casters brooch. A simple brooch design can be copied by pressing the brooch into moist clay. In this offprint, you then pour melted beeswax (Hedegaard 1989, pp. 74–5). Had the knot-shaped beasts been cast separately with the intension to rivet them on, a metal, wood or bone model for the drum would have been feasible. This would have called for a more time-consuming mould built up in three to five different pieces, but such work should have been fully within the ability of most Viking Age metal casters.

One possible compromise could be a hybrid model. This could be a hollow model in metal for the drum and four animals on top in wax, which would call for a separate mould piece for the very top of the drum. In this piece, the four wax animals are embedded. Just before the loam is so-called leather hard, the multi-piece mould is opened and the metal model taken out. The mould piece for the top would retain the four wax figures. However, such a procedure is likely to leave behind some small telltale clues on the surface of the finished brooch – these have not been observed on the original material with any degree of certainty. Thus it was decided to base the experiments on hollow wax drums complete with wax animals and wax rivets.

Mould A was built up over a wax model with kordel ornamentation using the same method as for a fason G 6 box brooch from the 1994 experiments, in other words a 'standard' two-piece mould (Figure 10). The only tangible and original Gotlandic material to take guidance from is one clay mould fragment for the top of a fason D 5/type 2a box-shaped brooch (Thunmark-Nylén 1983b, pp. 24–5) and some tiny metal flanges round the lower edge of the unfinished fason Gbl 3 brooch from Smiss (Zachrisson 1962, p. 209, Figure 5). The wax model for mould A, including a fixed wax-sprue, was placed on an oak plank. Here four small holes had been drilled to accommodate the four wax rivets; into the plank was cut a groove to take and support the

Figure 10. Mould A. Upper mould. Next to it, CuSi brooch, wax model with sprue for corner post and corner post cast in brass. Replicas.

Figure 11. A selection of Gotlandic and Scandinavian Viking Age brooches. All with the ability to sit flat. Replicas.

sprue. Following B. Lønborgs' definitions, the part of the mould that creates the ornamented impressions for the surface of the brooch is referred to as the *upper mould*; the part of the mould that creates the inside or the belly of the brooch is referred to as the *lower mould* (Lønborg 1998, p. 100). The majority of Viking Age brooches have the appealing ability to be able to 'sit flat' on a wooden plank (Figure 11). That would of course be after cutting holes to take protruding taps for the needle attachment, or in our case rivets. This feature was introduced during the 7th century AD and probably started with rectangular and round disc brooches. This fixation on the models greatly facilitated work on the upper mould pieces, especially for large brooches created from hollow wax models. Because once work is started with addition of a thin film of slurry, then impression loam in a layer some 0.2–0.3 cm thick, and later the more coarse regular mould loam in a layer up to 1.5–2.0 cm, the moist loam will start to lower the temperature of the wax. Pure beeswax becomes rather brittle below about 12°C. Sometimes the wax model cracks or a small wax knot-shaped animal breaks free of the drum. Round the edge of the upper mould that is in contact with the wood, you cut or press negative key holes.

The upper mould is allowed a night to dry. It is then turned over and work on the lower mould is started (Figure 12). As the inside of the brooch has no ornaments, the use of finer impression loam is not mandatory. However, original brooches cast using the textile cavity method (Hedegaard 2010b, pp. 90–1), as well as the few intact lower mould fragments that have been found in Scandinavia, indicate that it was done anyway. A depression in the lower mould ensures that during the early stages of the drying the loam can be pressed continuously and firmly against the inside of the wax model. Positive keys on the side of the lower mould are formed to fit

Figure 12. Mould A. Lower mould in progress. Notice depression in loam.

into the upper mould's negative key holes. In order to be able to subsequently separate the two mould pieces, a little dust from finely crushed used moulds is smeared onto the contacting surfaces.

Now the caster will have to decide whether to seal the two mould pieces or not. Sealing is simply an extra layer of regular mould loam. With no sealing, the mould pieces can be separated after the burnout of the wax, thus providing an opportunity to control the cavity for damage. The downside is that the caster then will have to seal the mould pieces with fresh loam, dry the mould again for about two days and burn it again for at least another hour. Short of time, the author chose the 'instant sealing' option. Under any circumstances, a clay mould of this size needs five days of drying. After this, the mould needs to be fired for some four hours. The firing takes place in an ordinary fireplace at about 700°C.

The drying period is *critical*. The moulds must be left to dry in the shade in a well-ventilated room. In this room, there should not be any strong, artificial heating. On very rainy days with high humidity, there is a risk that the drying process slows down or might even come to a full stop. If the moulds are not fired within ten to fourteen days, the manure and hair inside them might start to decompose, thereby reducing their porosity. Once the moulds are fired, they can be stored for a prolonged period. Later they are re-heated until they glow inside, as seen down through the inlet. Then, they are ready for casting. However, as fired porous clay moulds can be very fragile, one should store them accordingly and always limit transport and handling to a minimum.

Mould B was built in a different manner. Here the 'Smiss' CuSi-bronze replica drum with bare bands was tested in the role of a supporting metal model (Figures 13–14). It was placed on the oak plank and the upper mould was formed against it in three separate pieces, plus a separate piece for the top of the sprue. Later the pieces were removed and the metal model was replaced with a wax drum with kordel ornamentation. The still flexible upper mould parts were now applied to the wax drum. This was done to see if it was possible to improve the build-up of the upper mould and to spare the hollow wax model from abuse during the process.

The construction of mould B confirmed earlier observations. The porous mould-loam does not really necessitate a multi-piece mould. If it is decided to sacrifice a wax model, you then can wrap the model completely in mould loam, dry it, fire it and cast. If the inner layer of impression loam has been

Figure 13. Mould B. 'Smiss' replica-brooch tried as aid for separate top for upper-mould. Result partly negative.

Figure 14. Mould B. Adding slurry and impression loam with spatula and brush to knotty animals on wax model.

in close contact with the wax model, the cast result should be fine. It is interesting that it makes good sense to build up your mould like a multi-piece mould, whether your model is solid or wax. With a multi-piece mould, you have a much better contact between loam and model. As an added bonus, you can check a multi-piece mould for inside flaws before casting. These facts might explain why the majority of the mould fragments that we know from the Scandinavian Viking Age derive from multi-piece moulds.

Other moulds

Also produced were two-piece clay moulds for four corner posts and one bottom-plate. One-piece moulds were made for a needle and a centre boss. For these seven moulds, wax models were used. In particular, the flat bottom plate is a classic example of a metal object cast in a two-piece mould formed over a solid model.

The castings

All castings in the above-mentioned moulds gave complete and acceptable items (Figures 15–16). However, drum B has some minor flaws (Figure 17). When casting in mould B the caster (the author) overlooked a 20 g ingot of metal and did not get it into the crucible. As a result, there was barely enough metal in the crucible to fill the cavity of mould B. The very last metal in a crucible is always relatively cold and contains nearly all the impurities of the melt.

Figure 15. Mould A after casting. Ribe type 2 crucible and tong with pincer-like arms.

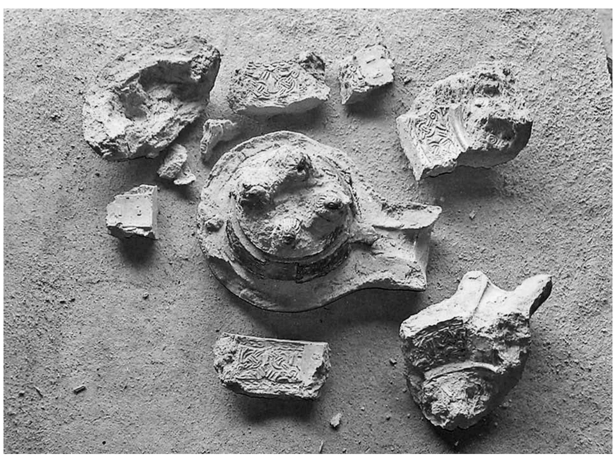

Figure 16. Mould B opened after casting.

Mainly due to shrinkage of the solidifying metal, all moulds partly cracked or even all together disintegrated after casting, especially if quenching in water was involved. A porous late Iron Age clay mould can only be used once in high-temperature castings of hollow copper-alloy brooches (Hedegaard 2010b, p. 92). Had it not been for the four animals, the making and the casting of the moulds for the drums would have involved the same level of difficulty as a standard, single-shelled oval tortoise brooch or an animal head-shaped brooch.

Drum A in the state of an unworked raw casting, but with the sprue removed, had an average thickness of 2.47 mm; its weight was 177 g. Corresponding values for Drum B' were 2.46 mm and 175 g. The average weight for a replica corner post with the sprue removed is 10 g. Today the original Fyrkat box-shaped brooch has a weight of 94 g, including corner post, lead, silver plating and conservation lacquer. Its drum has an average thickness of 2 mm. The outer measurements for drums A and B are within the parameters of the original brooch.

In theory, when taking some 20% of the weight of drums A and B due to the excess 0.5 mm in thickness, will provide some 140 g for each drum. This would have roughly been the original weight of the Fyrkat grave IV drum when it was a fresh, raw casting. The total weight of the 'complete' CuSi bronze fason Gbl 4 replica in Figure 9 is some 240 g. For comparison, a large trefoil brooch like the

Figure 17. Drum A and B. Flaws round inlet/gate on drum B due to impurities in melt.

Figure 18. Gotlandic brooches and needles on cape and dress. Box brooch fason P6/type 6b, animal head-type brooches type 7:4. Box brooch supported by two type 4b (Thunmark-Nylén 2006, p. 122) bronze needles. Replicas of bronzes from grave 127 at Havor, Hablingbo Parish. SHM 8064. NB: double-cape and dress does *not* derive from any original find.

type JP 115 'Tingelstad' would weight some 110 g (Petersen 1928, p.113, Figure 115).

It does not appear, however, that the casters on Gotland cared much for creating light advanced box brooches. The well-preserved Mårtens brooch (fason Gbl 5/type 7b) today weighs 327 g (Thunmark-Nylén 1983b, p. 381. 12151 Gröllingbo). Nor did the less advanced, but still large, box-shaped brooches with no gold foil and only a simple silver wire become light-weights, due to their having often been cast from an alloy with an average content of c. 19% lead (Thunmark-Nylén 2006, p. 381). In order to prevent these top-heavy brooches from sagging, it is reasonable to think that it was necessary for the women on Gotland to support their box brooches with two sturdy bronze needles passing through the cape and into the inner garments (Figure 18).

Encasing

Parallel to the work with the moulds, silver-encasing work was tried out on a drum with cast kordel ornamentation, a corner post and a centre boss, all cast in CuSi bronze. Sterling silver plates were annealed and hammered down to foil metal with a thickness of some 0.1–0.2 mm. Studying original box-shaped brooches in close-up, it is clear that the silver foils are not just lying flat on the positive-standing ornaments: the silver is also bent down around the ornaments, as can be observed on a fason G 6 from Stanga Parish (Figure 19). Using the brooch as a positive die and inserting a lead plate between silver foil and hammer, the silver is hammered down into the ornaments. It is important that the underlying ornaments begin to show on the surface of the silver. The silver foil is removed and cut into shape. After more annealing, the silver is replaced on the bronze ornaments. With specially forged pointed iron punches, so-called drifters, the silver is driven down into the groves and open spaces in the ornaments. Later the silver is tapped into the sides of the ornaments, this time with a more blunt punch using a spot-hitting technique. This method is what the author has chosen to label as '*pure encasing*'. A less refined and almost brutal process is driving the silver down onto a flat surface of a relatively soft copper-alloy. With a sharp punch, the metalworker forms the underlying ornaments through the thin silver foil as he goes along with

Figure 19. A 1524. Stanga Parish. Pure silver encasing. Foto Franceschi 2005. Fig. 175.

Figure 20. A 1524. Corner post. Here direct pure encasing. Foto Franceschi *et al.* 2005. Fig. 164.

his tool. The result can appear rather random (Figure 20).

During the trials with pure encasing, it became clear that the four animals on top of the drum posed as serious obstacles (Figure 21). It was necessary to construct a special wooden vice to hold the drum during encasing and cold work. This might explain

Figure 21. Attempted pure silver encasing on cast kordel ornamentation. Brooch seen upside down. CuSi replica.

Figure 22. Positive die with steep rope-cord ornamentation for producing silver plating. Replica.

why the original box-shaped brooch from Fyrkat was not given silver-plating work using the simple pure encasing technique. Under the partly torn off silver foil, no positive cast copper-alloy ornaments can be made out. The silver plating work had to be formed over specially made metal dies (Figure 22). The Fyrkat Gbl. 4 brooch's silver foil work called for no less than six or seven different dies. Thunmark-Nylén suggests a freehand ornamenting technique for the very thin silver bands (Thunmark-Nylén 1983a, p. 184). This technique was tested by the author, but with limited success.

The silver foils do not bend much around the bare positive bands on the original drum. This feature makes sense when it comes to soldering on the foil, due to vapour from the solder. The soldering of the almost flat silver plating was supported by fixing it with at least three identified silver rivets to the top of the original drum. The niello work must have complicated the soldering process. The mixture of sulfur, lead, copper and silver that constitutes the black metallic alloy, known as niello, fuses round 380°C (5). This means that high-temperature silver soldering was needed to hold the silver plating in place on the drum, the corner posts and the centre boss during the melt-in of the niello. The balance between the temperatures also had to take into account the gold amalgamation work on the drum, as the highly poisonous mixture of mercury and gold calls for temperatures between 357–375°C (Lønborg 1998, pp. 63–4). Work with niello and gilding was not undertaken during the 2015 experiments.

Conclusion

The research revealed that the maker of the original fason Gbl. 4 box-shaped brooch deliberately chose not to take any short-cuts. The four knot-shaped animals cast in one with the drum must be regarded as the common denominator because of them, an elaborate wax model, had to be sacrificed. This wax model was very time consuming in its making. The build-up of the mould and the casting became more complicated as more could go wrong. To encounter these problems the caster probably chose to work with a multi-piece clay mould, even if the lost wax method and the porosity of late-Iron Age clay moulds do not call for this. When cleaning the raw casting and cold working it with mini-chisels, engravers and punches, the animals made access difficult and slowed work down. The heads of the animals hovering over the drum's upper bands made it very difficult using the simple pure encasing method without damaging the animal figurines. So the silver encasing work on the original Fyrkat box-formed brooch had to be done separately, calling for several specially manufactured dies. The artisan behind this brooch did apparently not lack resources and time.

Apart from making it difficult for another caster to directly copy 'our' bronze-caster's work, from a combined archaeologist's and metalworker's point of view there seems to be only one logical explanation to the mentioned exertions. The artisan behind the box-shaped brooch from Fyrkat wanted to send a rather self-assertive message: 'Look what I can do; see how I master the wax, the mould loam, the brass, the silver and the gold!' Who had the metallurgical knowledge in order to fully appreciate the caster's talents? One group of people certainly did. This group was the other contemporary metalworkers on Gotland, as well as any metalworker outside of the island.

The casters of non-ferrous metals in the Viking Age gathered knowledge by studying each other's products. The finds from Viking Age centres of trade like Hedeby, Ribe, Birka, etc. indicate some regular export and import of cast brooches (Ambrosiani 1992, p. 37). A metal caster could also have procured exotic brooches through merchants dealing in scrap metal. A more 'direct trade', with almost brand new top-of-the-range box-shaped brooches, was certainly derived from plundering (Ulriksen 1997, pp. 210–11) (6). As there was a very limited market for an advanced box-shaped brooch outside Gotland in the 10th century AD, plunder is the most convincing explanation as to how the fason Gbl 4 brooch found its way from Gotland to Fyrkat. Every metal caster in Denmark would have loved to study it, but once the caster's curiosity was satisfied the now partly disassembled brooch was regarded as scrap metal. However, before the entire brooch ended up in a crucible, the Fyrkat seeress somehow intervened. She acquired the drum and had it made into a cup.

(1) The author would like to thank Jørn Svendsen and his crew at Skulpturstøberiet in Svendborg for access and help with the CuSi copper alloy box-shaped brooch castings. I would also like to thank Dipl. Praehist. Klaus Hirsch from Museum Sønderjylland–Arkæologi Haderslev for proofreading.

(2) Examples of metal analysed brooches: Fason G 2 box brooch. SHM 2286. 79.6% Cu, 16.1% Zn, 0.9% Sn + div. Oldeberg 1942–43 I, pp. 218–19. Fason D15/Type 2D box brooch. SHM 27739: 81.3% Cu, 17% Zn, 0.9% Pb + div. Thunmark-Nylén 2006, p. 381.

(3) Natural History and Paleontology Museum. Lergravsvej 2, DK6510 Gram.

(4) After a nasty parasitic infection acquired from bovine manure, the author has decided to stick to horse manure.

(5) It is, however, possible to make niello malleable at 200°C. See Lønborg 1998, p. 65.

(6) According to the 12th century AD Gutasagaen chapter 2, Gotland was 'in the heathen period raided by foreign kings'. Gotland officially became Christian in the year 1030 AD (Lindkvist 1983, p. 282 and Thunmark-Nylén 2004, p.165).

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