Viking Age Copper-Alloy Metal Casting

Scandinavian metal casting as performed between 800 C.E. to 1070 C.E. took many forms, including the use of a variety of copper based alloys, along with gold and silver. Of these, items of copper alloy are the most commonly found at archaeological sites and as a result, will be the metal-form focused upon in this paper. Of a larger focus, the study of experimentation with what little is known about Viking-Age metal-casting to test the theories posited by traditional archaeologists is also part of this analysis. It is often commonly stated, for instance, that Viking Age metalsmiths used some form of bronze, along with lost wax casting to make their intricately designed metal art. However, neither of these assumptions is entirely true. Viking Age copper-alloy metal casting, more often than not, involved the use of brass cast into two-part clay moulds which were formed around extant objects, whereas bronze finds are rare; and the lost-wax casting method, while likely used especially for less detailed items, cannot be proven to have been used very often, if at all.

Foundational to the understanding of Viking-Age metal casting is the art involved in the composition of the metals. Copper alloys, by definition, contain a base of copper. The composition of the final alloy is determined by the addition of certain other metals. For instance, an alloy consisting of 40% percent to 90% copper, with the rest being zinc (or to a lesser extent, lead), creates brass. A mixture consisting of 70% to 80% copper, with the rest being tin, creates a bronze alloy; whereas only 10% copper mixed with tin (or lead), creates an alloy of pewter. Within these alloys, other additives can also be incorporated, creating a variety of alloys. The alloy created is determined by what the caster has on hand, the cost they are willing to invest in the project, and the properties (such as color and malleability) required by the design. Existing evidence demonstrates that the most commonly used copper-alloy employed by Viking Age metalsmiths, was in fact what today would be considered 'classical brass.'

The production of bronze was an ancient art by the time the Viking Age began. The Phoenicians and Romans utilized bronze alloys both with and without tin, regularly exporting tin from

England, but the proliferation of English tin had decreased by the Viking Age. One can postulate several possible reasons for this lack of English tin in Scandinavian casting, but there is very little evidence to confirm any theory with certainty. It can only be said that tin was not as common a commodity in Scandinavia after 600C.E.[1] Regular attacks by the Danes into England during the period may have limited the will of Saxon miners to trade a valuable commodity to Scandinavians in general. Godwn and Edmund, (sons of King Harold), for instance, closed down English tin mines in 1068 C.E., as a result of constant invasions by Danish warriors.[2] Presumably, earlier English rulers who also were in a constant state of war with Scandinavian raiders could have done the same thing, which would explain the lack of local tin coming out of England, at least into Scandinavia. It is also possible that Scandinavians simply preferred zinc or lead over tin in their copper alloys and that trade in tin was not the reason for the lack of its use in Scandinavia. Whatever the case, the fact remains that a great majority of mass-produced copper alloy items in Scandinavia are more consistent with brass than bronze, due to the use of zinc, as opposed to tin.

According to Anders Söderberg, zinc-based alloys were the most common consistency of metal in archeological finds between 500-900 CE.[3] In addition, Pare's analysis of the metallurgy of 520 Bronze-Age graves North of the Alps shows that over 200 copper alloy finds had no tin at all, only 8% had more than 1% tin, and less than 5% had more than 4% tin.[4] Furthermore, Dungworth and Nicolas assert that throughout the Viking Age and into the 14th century, most "bronze" objects in Europe were actually a leaded antimony copper, often with little or no tin added at all.[5] Finally, Söderberg notes that a correct English terminology for Viking-era alloys, would be gunmetal (brass + Sn) leaded brass (brass + Pb), and leaded gunmetal (gunmetal + Pb)."[6]

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[1] Lewis, G. R. The Stannaries: a study of the medieval tin miners, by Lewis. Harvard University: D. Bradford Barton, 1908. 26.
[2] Lewis, 27.
[3] Söderberg, Anders. "Scandinavian Iron Age and Early Medieval Ceramic moulds – Lost Wax or Not or Both?" Scandinavian Iron Age and Early Medieval Ceramic moulds. (2012).
[4] Pare, C. F. E. Metals Make the World Go Round: The Supply and Circulation of Metals in Bronze Age Europe. (Oxford: Oxbow, 2000).
[5] Dungworth, David, and Matthew Nicholas. "Caldarium? An Antimony Bronze Used for Medieval and Post-medieval Cast Domestic Vessels." In Historical Metallurgy, 24-34. Vol. 38. (Harmondsworth, Middlesex: Historic Metallurgy Society, 2004).
[6] Söderberg, Anders. "Viking Metal Casting." Viking Metal Casting. April 30, 1999. Accessed January 21, 2017.

Interestingly, it was not until fairly recently that zinc could be separated from its ore and formed into an ingot through a smelting process. Therefore, due to a process discovered by the Romans, zinc ore was inserted into the copper mix until the zinc vaporized out of the ore, infusing into the copper.[7] This form of zinc and copper alloy created hard enough brasses to be what some would refer to as “Classic Bronze.”[8] Interestingly, this kind of brass was desired by the Romans specifically because, when mixed correctly, resembled gold in color.[9] With the metals discussed, the next step in re-creating the metal casting process of the Viking Age is to look at the furnaces.

Viking-Age furnaces found by archaeologists show only the final stages of what must be a fairly complicated process. The extant fragments, along with evidence on rune-stones that show forges and tools in use, provides excellent evidence for the probable process, however. A metalsmith’s furnace typically consisted of a tight grouping of gathered stone, clay and sand placed into a circle to form a pit, into the center of which a crucible containing the metal will be placed.[10] Hardwood charcoal is gathered below and around the crucible containing the metal to be melted. A clay tube called a “tuyere,” is inserted through a furnace wall and into the outer layer of the charcoal, which will be used to funnel air into the furnace. This tube will stick out of the furnace at least 6,” and a bellows of some sort will attach to the outside end. The clay “tuyere” is a way to connect the metal, wood, or leather end of the bellows to the furnace without damaging the bellows due to extreme heat.[11] Just like with any high-temperature metal casting furnace, there must be *no* escaping flame from the sides if the melt is to get up the required 1800 degrees Fahrenheit for casting. A small air-hole at the top is required and recommended from experimentation by the author of this paper. Some flame will escape from that hole, but only after fully engulfing the crucible. To stoke the flame into a

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[7] Bork, Robert Odell. De Re Metallica: The Uses of Metal in the Middle Ages. (Aldershot, Hants, England: Ashgate, 2005). 3

[8] Söderberg, Anders. "Viking Metal Casting." Viking Metal Casting. April 30, 1999. Accessed January 21, 2017.
Note: Zinc (much more so than copper or tin) is an incredibly toxic metal, and it is recommended that persons looking to re-create the casting process simply use modern silica or tin-alloy bronze, unless they have a good quality full-face respirator and an open area within which to smelt.

[9] Pare, C. F. E.

[10] Bencard, Mogens, ed. *Ribe excavations 1970-76*. Esbjerg: Sydjysk Univ.-Forl., 1984: 93

[11] Bencard, Mogens, Lise Bender Jørgensen, Helge Brinch Madsen, and Aino Kann Rasmussen. *Ribe excavations 1970-76*. Jutland Archaeological Society, 2004: 187-192

high heat around the crucible, the bellows will need to be worked continuously until the metal is liquified.

The bellows do not need to be particularly large, but, if the bellows are small, more than one will be needed. At the historic site of Haithabu, for instance, the metalsmith used a double-bellows which connected to the same tuyere, and pumped them one at a time, fairly slowly, keeping a continuous flow of air into the furnace.[12] The double bellows method is documented on the Sigurd Runic Carving, in Sweden (see below).[13] Once the furnace has been mastered, the next, and perhaps hardest part of this entire process, is to understand the mould-making and casting procedure, to which there is an ongoing debate in the archaeological community.

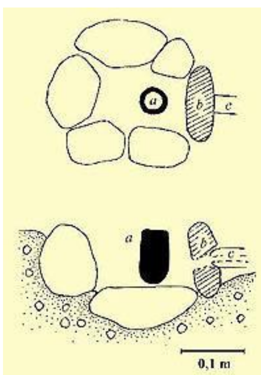

Image 1: Hearth: a) Crucible. b) Tuyere, nozzle.

Image 2: Sigurd Fafnesbane with tools and bellows. From the Sigurd Runic carving, 1030CE Sweden.

Image 3: Recreation of Viking-era hearth.

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[12] *Bronze Casting at Haithabu*. Denmark: Haithabu Museum and Historic Site. Film. Note: Anyone trying this method should be aware that not all 'fireplace' bellows are sold with a valve to keep air from sucking out of the furnace and into the bellows during re-inflation. For the most part, such bellows are too small for casting. If tried, however, it is important that the caster positions the bellows slightly back from the tuyere opening to provide a safe gap for air to flow back into the bellows during re-inflation.

[13] Bencard, Mogens, et. al: 192

The mould for Viking Age copper alloy items can be made in two ways: clay-based two-part mould with an impression from an already extant object, or a clay-based one-part mould with a lost-wax original in it. If the second option is used, then the caster would simply heat the mould, let the wax drip out, and then fill the empty cavity with metal. There is a debate among archaeologists on which was most often used and how practical each method was for mass-production. Traditional archaeologists tend to stick with the idea that lost wax was used, but do not provide evidence or a method to this assumption. The experimental archaeologist, following extant mould pieces found in archaeological site, tend to side with the two-part mould made from a hard object that is removed prior to casting.[14] More about the controversy will be discussed further into this paper. Either style can be used with success, as long as the mould is properly made.

What is most important about the composition of the clay moulds is that if made wrong, they will crack and fall apart as they dry. Another important part of the process is that all moulds must be heated to at least 800 degrees before taking the melt, or they will “explode” during the casting. The reason for this is that chemically bonded moisture will remain in clay until it reaches over 800F, and moisture reacts violently to 1900F metal.[15]

For the mould to survive the heating process requires some finesse on the part of the metalsmith. Firstly, the mould is based upon some type of clay, but the type of clay, but there does not seem to be a specific “one type works best” clay to use. A well-respected metalsmith (relied upon for this paper because he takes great care to analyze clay moulds used for brass and bronze casting), Cannoccio Biringuiccio,[16] was a bit obtuse on this factor: “with the exception of pure clay, any other earth, if free from pebbles, could easily serve you by tempering it with others.” Biringuiccio continues: “Aside from actual trial, I believe that there is little that can help you, since the clay in itself has no color or visible sign that I know of to show how

[14] Smith believes that solid items were copied in two part moulds (many of which have been found in archaeological sites), whereas Hedegaard believes that the primary form of casting was single moulds with lost wax in the middle, of which no evidence has been found.

[15] Meeks, Nigel, Caroline Tulp, and Anders Söderberg. "Precision lost wax casting." *Experimental and Educational aspects of Bronze Metallurgy*, 2001: 10

[16] In the current day, copper-alloys are typically cast in pure sand or high-temperature silicone, making clay moulds fairly rare. The earliest writings in regards to clay-based moulds, therefore, tend to be well-published European artisans from the high Middle-Ages or later. Though this is well past the Viking Age, the concept is the same: clay and other additives are mixed to create a mould that can take high-temperature copper alloy metal. Masters such as Cannoccio Biringuiccio analyzed their art extremely well, which gives a window into the general techniques of the era in general. Unfortunately, Viking Age masters left only fragments, so reliance upon later artisans becomes far more important.

satisfactory it is, you see, one is white, one black, one yellow and another red."[17] Biringuccio, of sixteenth century fame, extant fragments from Viking Age furnace sites, along with present-day researchers, Anders Söderberg and Michelle Smith, all agree that quartz sand, manure and wool or hair are required for these moulds.

The biggest problem with pure clay moulds, of course, is that they shrink when drying, which disfigures them. Additionally, only clay with silica in it can withstand the high temperatures needed for casting. Silica clay is not available everywhere, so adding quartz or silica to most commonly found clay becomes a necessity. Literally 40% of the clay moulds, according to Michelle Smith, must consist of quartz sand (which changes the composition of the clay greatly).[18] It is thought by Smith that the quartz sand provides a refractory ability, and that the other organic materials provides a form of portal for gasses to escape through as they carbonize on the pouring process.[19] Biringuccio supports the need for organic material by instructing in his manual that 2/3rds of the moulds should consist of wool-cloth fragments (or hair or manure).[20] Regardless, it will take some experimentation by the caster to get this mixture right, and can be the single most frustrating part of re-creating Viking Age metal casting. What makes the issue of mould-making even more challenging is that apart from the clay mixture, there is currently a debate over what type of moulds Viking Age metalsmiths employed: two-part moulds made from an existing item, or a single mould build around a lost wax model.

Both Smith and Söderberg have published their experimentation with two part moulds, fragments of which are extremely common archaeological finds at Viking Age furnace sites. There is a modern language used for moulds which should be stated for any further study to be clear. A mould that has two sides is called a 'two-part' mould. The 'top' side is known as a "cope," and the bottom side is called a "drag." In a two part mould, the design could be in one side or the other, or both. An item being copied, such as something that already exists, or a model made of some kind of hard material, is called a "tool." The casting style for clay moulds, where an existing object is pressed into it and later removed before casting is called a "direct-matrix" method. There are many more terms of course, all of which are fairly modern. Knowing them helps with

[17] Gnudi, Martha Teach., Vannoccio Biringuccio, and Cyril Stanley. Smith. The Pirotechnia of Vannoccio Biringuccio: The Classic Sixteenth Century: Treatise on Metals and Metallurgy. (Estados Unidos: Dover Publications, 1990): 219
[18] Bork: 10
[19] Bork: 14
[20] Gnudi, Martha Teach: 218

understanding archaeologists as they discuss the mould making process. However one might term the parts of a mould, it is the composition that makes all the difference.

What is specifically needed for a direct-maxtrix two-part mould are two slabs of clay mixed with quartz sand and organic material, a tool (which is the item being copied, such as a model or existing object), and some fine slip.[21] The fine clay slip is placed along the facing side of the mould, which will capture details of the item being copied clearly (remember that the mould will be fairly course, due to sand and organic materials). Then, the tool is pressed into the facing side and allowed to dry. If the tool is being copied exactly (such as a wood, bone, clay or original exact copy), the other back-facing slab is pressed over the tool and moulded to the sides of the facing piece. An added task is to carve into the moulds “keys” along the edges of the mould halves, so that when they dry they can be reassembled exactly, and “Sprues,” which is the one or more funnels into the mould in which the metal will be poured. Once complete, the mould halves will be allowed to dry. Next, the two pieces are separated, the tool removed and then a knife can be used to insert pin-mounts if required. Then, the two halves are placed back together and the whole assembly is covered in a shell of mixed clay to seal it. Once completely dry, the mould will be slowly fired up to around 800 degrees and the metal poured slowly in.

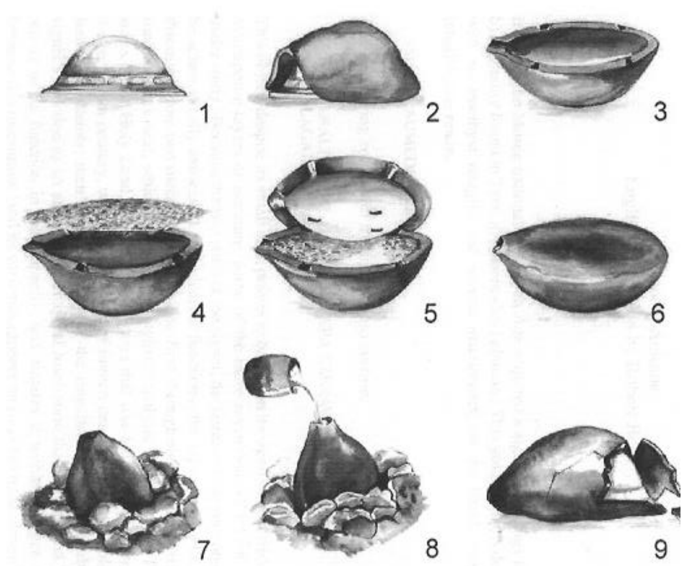

Image 4: Diagram of an oval ”turtle” brooch mould.

[21] This tool, or master copy, can be made of any hard substance, including wood, bone, metal and stone.

Note that for oval brooches, there is an additional step, which includes leaving a piece of wool inside the back piece of the mould. So many oval brooch moulds have been found with the marks from the wool cloth that Smith wanted to figure out why it was there. It should be noted that of all the academics who have written about Viking Age oval brooches, Michele Smith is the only person to try to figure out what the wool cloth was for. Other archaeologists supposed it was just put there as a tradition, but never stated why.

What Smith found with her experimentation is that the thick wool cloth provided two functions. One, in the case that there is only a master tool with no back (like a block with a facing impression on it, but no back, etc), the inserted wool cloth provided an item thickness for which to press the back mould piece onto. The other use of the wool cloth, which was left in the mould after the two halves here assembled together, was to provide a sacrificial carbonizer, meaning that as the molten metal flows into the mould, the wool instantly carbonizes and uses up oxygen in the mould. The one thing all hot-metal casters know is that oxygen is an enemy of high-temperature casting, because it acts as a block to the gasses and metal being poured into the mould.[22]

Image 5: Back of extant brooch with wool fabric pattern embedded, courtesy of the Royal Museum of Scotland.

Besides two-part clay moulds, archaeologists imagine that lost wax casting was also used by Viking Age metalsmiths. While this is absolutely logical, lost wax casting is almost impossible to prove, as the wax is destroyed during the mould heating process. Of all extant Viking Era grave finds, only one hinted at wax casting. It consisted of a man with a block of beeswax, a variety of carving and casting tools, and gold ingots.[23] It can be surmised that this grave assortment pertained to gold casting, but still provides no evidence that the lost wax method was used in Viking Age brass casting. Archaeologists have assumed (until recently) that lost wax was the obvious casting method used by casters of this period, yet only two-part mould fragments have

[22] Gnudi, Martha Teach., 92
[23] Söderberg, Anders. "Scandinavian Iron Age and Early Medieval Ceramic Moulds - Lost Wax or Not or Both?" Scandinavian Iron Age and Early Medieval Ceramic Moulds - Lost Wax or Not or Both? | EXARC - Journal. 2013. Accessed January 21, 2017.

been found.[24] *Two-part moulds are unnecessary in lost-wax casting*, which therefore challenges the common assumption regarding lost-wax casting being commonly used by Viking-Age casters. Furthermore, archeological studies have shown that Viking-Age metalsmiths absolutely plagiarized off of each other. This is to say that after a set of brooches was made, for example, another metalsmith at another site might desire to copy that item, but from an existing piece. This results in a slightly less-detailed item, since it was not made with the original tool. Archaeologists have been able to trace the path a number of styles went by looking at what seems to be items all based on one original style, but in decreasing levels of detail over time.[25] To do this kind of casting requires direct-matrix two-piece moulds as well, which further lessens the common argument about the general use of lost-wax casting in general. Because lost-wax casting probably happened, however, it is important to discuss the debate amongst academic archaeologists and experimental archaeologists about how this process was done, for what types of items, and why.

Image 6: preparing a lost-wax mould for simple item requiring minimal detail and effort.

Although a number of experimental archaeologists believe that making moulds from wax would be overly time-consuming (making a wax model for every new casting would take a great deal of time, and wax would be too fragile to use as a re-usable tool),[26] academic archaeologists have posed interesting methods that ‘could have’ been used for mass production. This argument mostly centers around complicated items, such as turtle brooches. The most plausible of the mass-production lost-wax methods is posed by Ken Hedegaard. The Hedegaard method involves making one original piece (from any desired process), making mould from that piece, and then using that mould only to make wax copies from. Then those wax copies, which

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[24] Ibid.
[25] Bork: 85
[26] Bork: 84

cool quickly, can be removed from the mould and used as the tool for a lost wax mould. This method, Hedegaard believes, would aid in rapid mass-production of moulds for lost-wax brass casting.[27]

Michelle Smith disagrees with this idea, however, for the simple reason that pulling cooling or cooled beeswax from a clay mould is very difficult without warping or destroying the wax, which is fragile and has fairly adhesive qualities. Smith furthermore notes that experiments with using animal fat or grease would facilitate the removal of the wax from the mould have generally failed thus far (a result also experienced by the author of this paper).[28] While Smith makes excellent points, archaeologists at the Ribe historic site support Hedegaard's theory in that they (only twice) successfully created wax tools from a clay mould. Their recipe involves pouring thin layers of wax until the required thickness is attained (being careful to never letting any of the layers cool). Then a piece of cloth is attached to the back of the still hot wax wax so it sticks, and the cloth and wax tool are carefully peeled away from the mould. When everything goes right, this can theoretically be done over and over again until the mould needs to be replaced.[29] It is important to note that neither Hedegaard or any other published archaeologists has replicated their posited lost-wax theories, and the archaeologists at Ribe have yet to publish a study in which they show that they successfully produced dozens of wax tools in a day from one mould in using their painstaking process. On the other hand, Michelle Smith and Anders Söderberg both have performed and published studies on multiple forms of wax-tool casting. Both agree that wax was possibly used as a tool for simpler items (flat keys or trefoils, for instance), whereas more complex items, such as turtle brooches, very likely utilized a different form of production.

The method of lost-wax casting currently accepted by historical-archaeologists currently attempting to replicate the Viking Age casting process believe that if wax was used for complex items such as turtle brooches, then the craftsman would make one detailed wax tool, which would be then placed into a one-piece clay mould. The wax would then be melted out and the metal poured in. At this point, the metal original would be used to make multiple other castings via the two-part, direct matrix mould method.[30] There is a great deal of evidence that Viking Age metalsmiths made moulds from metal originals, which makes this method a reasonable consideration.[31] The main difference between Hedegaard's wax-copy method and Michelle Smith's

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[27] Söderberg, Anders. "Viking Metal Casting." Viking Metal Casting. April 30, 1999. Accessed January 21, 2017. http://web.comhem.se/vikingbronze/casting.htm.
[28] Ibid.
[29] Bencard, Mogens, ed.: 92
[30] Söderberg, Anders. "Viking Metal Casting." Viking Metal Casting. April 30, 1999. Accessed January 21, 2017.
[31] Bork: 86

direct-matrix (two-sided mould) method is that Hedegaard's method (he claims) could produce 120 wax copies per hour.[32] In real-world experimentation, Soderberg found that it took one hour and twenty minutes to fully make one mould using the lost-wax method.[33] While this idea makes sense, the question to ask in this case is simply, how many cast items did a metalsmith really need to make in a given week or month to make a living during the Viking Age? Are archeologists such as Hedegaard creating Viking Age manufacturing theories that apply to the needs of an industrial economy, as opposed to a pre-industrial rural crafting economy? Until someone successfully replicates a mass-production wax-tool method, or at least discovers actual evidence of this process, it must be ascertained that the archaeological evidence and experimental practice, which supports the use of two-sided clay moulds based upon metal original pieces (or a hard copy of some sort), must have been the most common form of production for complex copper-alloy castings.

An interesting statement made by Michelle Smith at the end of her study of experimental archaeology in turtle-brooch production was simply that archaeologists often lack a practical insight in the crafts of past peoples. The subtleties of culture and economic realities need to be considered before simply asserting how items were created by the craftsmen of a given period.[34] Historical archaeologists are helping to provide that practical insight, however. Knowing that Viking Age copper-alloy metal casting primarily utilized brass cast into two-part clay moulds which were formed around extant objects gives those that wish to truly engage in historical replication a place from which to begin their efforts.

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[32] Söderberg, Anders. "Scandinavian Iron Age and Early Medieval Ceramic Moulds - Lost Wax or Not or Both?" Scandinavian Iron Age and Early Medieval Ceramic Moulds - Lost Wax or Not or Both? | EXARC - Journal. 2013. Accessed January 21, 2017.

[33] Ibid.

[34] Bork: 93

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Image 1 Furnace Diagram. Source: Söderberg, Anders. "Viking Metal Casting." Viking Metal Casting. April 30, 1999. Accessed January 21, 2017. http://web.comhem.se/vikingbronze/casting.htm.

Image 2 Sigurd rune-stone, Sweden. Image source: Bencard, Mogens, Lise Bender Jørgensen, Helge Brinch Madsen, and Aino Kann Rasmussen. Ribe excavations 1970-76. Jutland Archaeological Society, 2004.

Image 3 Recreation of Viking-era hearth. Source: Soderberg: http://web.comhem.se/vikingbronze/

Image 4 Direct-Matrix casting of a turtle-brooch. Source: Bork, Robert Odell. De Re Metallica: The Uses of Metal in the Middle Ages. Aldershot, Hants, England: Ashgate, 2005.

Image 5 Evidence of wool textile in brooch manufacture. Source: Bork, Robert Odell. De Re Metallica.

Image 6: Preparing a lost wax mould. Source: Söderberg, Anders. "Scandinavian Iron Age and Early Medieval Ceramic Moulds - Lost Wax or Not or Both?" Scandinavian Iron Age and Early Medieval Ceramic Moulds - Lost Wax or Not or Both? | EXARC - Journal. 2013. Accessed January 21, 2017.