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Hollow comb rivets made from strip-drawn copper wire and two possible antler draw plates from 11th–12th c. Sigtuna, Sweden

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Modern metal wire is produced by drawing solid metal rods through a draw-plate. Scandinavian smiths used this technique already during the Viking Age, but little is known about earlier Scandinavian methods for making metal wire. It has previously been suggested that the metal rivets in composite bone and antler combs may have been hollow and produced by strip-drawing, but no metallurgical studies have so far been carried out to investigate this possibility. Here, we used scanning electron microscopy (SEM) to investigate copper-alloy rivets in 11th – 12th c. composite combs from Sigtuna, the administrative centre for middle Sweden’s first Christian kings during the early Medieval period. Our SEM images showed that while some rivets were made from solid circular wire, other rivets are hollow and probably manufactured from strip-drawn wire. We also examined two perforated antler plates, likely dated to the 12th c. and excavated from a bronzesmith’s workshop in the block Trekanten in central Sigtuna. The copper and lead particles detected by SEM analysis around the plates’ holes indicate that the plates were used in metalworking activities. Because the holes are cylindrical and not conical, however, the plates would not be viable tools for drawing solid metal wire. In the strip-drawing technique, on the other hand, cylindrical holes might have been used to produce hollow metal wire. The holes in the studied antler plates have the same diameter – 2.0 mm – as many comb rivet holes, possibly suggesting a standardization for large-scale production. The bronzesmith’s location next to a combmakers’ workshop provides further support for a production connection between the two crafts. Taken together, our results indicate that the two perforated plates may have been tools for strip-drawing copper wire, used to make comb rivets.

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Introduction

In modern society, metal wire is produced by drawing solid metal rods through conical holes of increasingly smaller dimensions (Carroll 1972; Newbury & Notis 2004; Oddy 1977). Each drawing step reduces the diameter of the wire, until the desired size is obtained. This wire-drawing technique was known in Scandinavia already at the Viking Age, as demonstrated by the draw plates encountered in Viking trading centres such as Birka (Arrhenius 1968), Hedeby (Armbruster 2012), and Staraya Ladoga (Davidan 1982).
Little is known about earlier Scandinavian techniques for crafting metal wire. In other cultures, a variety of techniques were used to produce metal wire before the invention of wire-drawing (Muros et al. 2007; Newbury & Notis 2004; Oddy 1977; Scheel 1989), such as hammering, casting, block-twisting, strip-twisting (Carroll 1972; Thouvenin 1971), strip-drawing (Williams 1924), and roll-drawing (Özsén & Willer 2016). Clarifying which wire-making techniques were used where and when is important not only from an archaeometallurgical point of view, but may also aid when determining the provenance and authenticity of ancient jewellery and other objects containing metal wire (Carroll 1970; Ogden 1983).

A study of metal wires from the Viking Age town of Birka, Sweden, showed that most were produced by drawing, although occasional pieces of jewellery contained block-twisted, strip-twisted, and strip-drawn wire (Duczkó 1985). As Birka was an international trading centre (Ambrosiani 2012), many objects were imported from faraway places (Wärmfländer et al. 2015), and it is not clear which of the wires studied by Duczkó (1985) were locally produced. Some researchers of Viking Age and Medieval composite bone and antler combs in Norway (Hansen 2005), Sweden (Ros 1990), and the British Isles (Galloway 1990) have noted that many of the comb rivets appear hollow, and suggested that they might have been produced from metal wire manufactured with the strip-drawing technique. Unfortunately, no metallurgical studies have so far been carried out to investigate this suggestion, which is in conflict with Duczkó’s (1985) conclusion that by the Viking Age, the technique of drawing solid wire had replaced earlier Scandinavian techniques for wire production. Consequently, Duczkó (1985) argues that objects containing non-solid wire should be pre-Viking Age. In his study of comb rivets from Birka, Stjerna (1998) observed longitudinal striations on some rivets, indicating they were made from drawn wire, but he did not carry out cross-section analysis to determine if the rivets had been made from solid drawn wire or from hollow strip-drawn wire.

Sigtuna was middle Sweden’s administrative centre for the early Medieval kings, and an important centre also for craftspeople and artisans. Many researchers have used Sigtuna’s rich archaeological material to investigate Sweden’s Viking Age and early Medieval crafting technology (Edberg 2013; Floderus 1928; Karlsson 2016; Pettersson 2007; Ros 1990; Sjöbeck 2016; Söderberg 2006; 2011a; Söderberg & Gustafsson 2007). Here, we investigate copper rivets from composite antler combs excavated from 11th–12th c. Sigtuna, in order to characterize the manufacturing technology and chemical composition. We also investigate two perforated antler plates, excavated in 1925 from a bronzesmith’s workshop in central Sigtuna, and proposed by Floderus (1928) to be draw plates used to produce metal wire. The objects are studied with scanning electron microscopy (SEM), a very useful technique for characterizing residue particles, corrosion, tool marks, and elemental compositions of archaeological objects as well as modern replicas (Bartelink et al. 2015; Boutrup et al. 2013; Scott et al. 2009; Smith et al. 2018; Smith et al. 2015).

The strip-drawing, roll-drawing, and wire-drawing techniques

Some of the various techniques that exist for producing metal wire involve drawing the wire material through a small hole. Wire produced with such methods, which involve strip-drawing, roll-drawing, and proper wire-drawing, but not block-twisting, strip-twisting, hammering or casting, will therefore display longitudinal striations along the wire surface, created by the unevenness in the holes of the draw plates. The strip-drawing and roll-drawing techniques furthermore create a longitudinal seam on the wire surface, which might be more pronounced than the striations. Yet, separating these techniques based on visual inspection of the wire surface is a very difficult task (Carroll 1970; Newbury & Notis 2004; Oddy 1977; Ogden 1983; Özsén & Willer 2016). Instead, a cross-section analysis is much more informative. For proper wire-drawing, the transverse cross-section is solid (fig. 1B), and the longitudinal cross-section displays elongated grains (Oddy 1977). For strip-drawing, the transverse cross-section is hollow and slightly spiral-shaped (fig. 1A), while the grains in the longitudinal cross-section should not be significantly elongated. For roll-drawing...
the transverse cross-section is distinctly spiral-shaped (Özsen & Willer 2016), possibly with a small void in the centre (fig. 1C).

In proper wire drawing, each drawing step reduces the diameter of the solid wire and increases its length. Thus, the corresponding draw plates, which must be made of a material at least as strong as the wire itself, typically display series of conical holes of decreasing diameters (Newbury & Notis 2004; Oddy 1977). The strip-drawing method, known from Ancient Egypt and the Roman Empire (Carroll 1972), involves less strain than proper wire drawing, due to the hollow interior of the wire. Thus, strip-drawing does not significantly increase the length of the wire, even if multiple pulls are conducted to gradually reduce the wire diameter. It has been suggested that draw plates for strip-drawing could have been made from relatively soft materials such as wood or bone (Oddy 1977; Williams 1924), and conical holes are likely not required—cylindrical holes may suffice. Although these assumptions could be supported by future experimental evidence, they will remain speculations until draw plates for strip-drawing have been identified in the archaeological record, which to our knowledge has so far not happened. The roll-drawing method was only recently described (Özsen & Willer 2016), and the material properties required of draw plates for roll-drawing are currently unknown. It can be assumed that roll-drawing should require less force than drawing solid wire, but more force than strip-drawing hollow wire.

**Sigtuna combs and comb fragments**

Sigtuna’s archaeological record includes a multitude of combs and comb fragments of different types: 4000 such finds are recorded in the Sigtuna Museum database. About one hundred are intact combs, while the rest are fragments and semi-manufactures, mainly made from antler. One common type is the Scandinavian early Medieval single-sided composite comb, which corresponds to Ambrosiani’s (1981) type B and Broberg & Hasselmo’s (1981) type 1 (fig. 2). Numerous finds of components for this comb type, including used tooth plates with remains of rivets, semi-manufactures for connecting plates, and tooth plate semi-manufactures that appear to be unused, were found in 1925 at an excavation in the block Trekanten conducted prior to the installation of Sigtuna’s first water conduit system (Arbman & Floderus 2005; Edberg 2018). Four tooth plates excavated from the Trekanten trench B (finds SF 407:b:1, SF 407:b:2, SF 435:f, and SF 561:e) are shown in figs. 3–5.

The trench at the block Trekanten revealed a bronzesmith’s and a combmaker’s workshop, situated close to each other. Due to the poor documentation of the early Sigtuna excavations, the stratigraphic dating of these contexts is somewhat unclear. Much of the comb making debris appeared in trench sections B:V and B:VI, but a fair amount was together with the bronzesmith’s waste in sections B:II and B:III (Arbman & Floderus 2005, pp. 17; cf. Edberg 2018, p. 6). It is therefore difficult to distinguish the two activities from each other, based on the excavated material, but this may not be due to poor documentation in the 1920’s. Instead, it might reflect a low level of crafting specialisation during the early Middle Ages. Different crafts could be housed under the same roof, and they could possibly also be performed by the same craftsmen (Hansen 2015; Ros 1990).

In the nearby block Trädgårdsmästaren, single-sided composite combs with few but thick copper-alloy rivets (fig. 2), typically two per tooth plate, were common during the 12th and early 13th c. Iron rivets dominated in Scandinavian combs during
the 11th c. (Smirnova 2005), which is clearly illustrated by the material from the Trädgårdsmastaren block. Fragments of combs of a similar type, with copper rivets and dated as early as to the second half of the 11th century, were excavated in 2014 at the Götess mack site. Being more recently conducted, this excavation has proper stratigraphic documentation. One fragment (181:3205:247) was found in connection with a bronze workshop belonging to building phase V, i.e. 1080–1150 AD, and another fragment (268:1:251; fig. 6) was found in a waste dump belonging to phase IV, i.e. 1060–1080 AD (Hed Jakobsson 2017, pp. 41, cf. the Excel sheet “Matris med fasindelning” on the CD disc). An antler workshop involved in the manufacture of single-sided composite combs and simple double-sided combs was connected to the same chronological phase. A direct contextual connection between comb fragment 268:1:251 and the workshop is however not certain.

Overall, a fair dating of the workshops in Trehörningen would be the late 11th or the 12th century. This dating correlates with the circumstances in Trädgårdsmastaren, where antlerwork flourished during the 12th c. (Pettersson 2007). The depth of the finds from the bronzesmith’s workshop, i.e. 1.0–1.2 meters below the 1925 street level (Floderus 1928), may roughly correlate to such a dating. The dating is compatible also with the presence of the simple double-sided comb among the finds from these layers, a type that started to appear in Sigtuna during the second half of the 11th c. (Wikström 2005) and became common during the 12th c.

**SEM analysis of the comb fragments**

Scanning electron microscopy (SEM) images and SEM-EDS spectra were recorded with a Hitachi TM-3000 table-top SEM unit, operating at 15 kV and equipped with a large sample chamber. Thus, the entire objects were inserted into the SEM unit and investigated without surface-coating or other preparations at low vacuum (i.e., in
SEM images were recorded in back-scatter mode where solid metal, metal residue, and metal corrosion appear brighter than the surrounding bone or antler matrix. SEM-EDS analysis was used to map and calculate metal compositions.

For tooth plate SF 561:e, the two rivets appear hollow upon visual inspection, and this impression is confirmed by the SEM imaging (fig. 3). Both rivets appear to be around 1–1.5 mm in diameter, with a metal sheet thickness around 0.2–0.3 mm and central voids with irregular shapes that have average diameters around 0.5 mm. Although both rivets are corroded, their central voids cannot reasonably have been created by corrosion processes, which typically are initiated at an object’s exterior surface. Instead, the most likely explanation is that the rivets were made from hollow wire, such as that produced by the strip-drawing technique (fig. 1).

For tooth plate SF 407:b:1, the SEM analysis shows that both rivets are completely corroded: no solid metal is present (fig. 4). A close-up SEM image of the right rivet shows a series of concentric circles, remaining as structural features in the corroded material. The key feature appears to be two generally circular layers, each around 0.1 mm thick and rich in copper. These two layers encircle an oval boulder-shaped central feature, about 1 mm across and copper-rich (fig. 4). We interpret this as the corroded remains of a hollow rivet made from strip-drawn copper wire. The two circular layers in fig. 4 would then correspond to hollow wire made from two layers of copper strip, and the central boulder-shaped feature is corrosion (possibly mixed with soil/dirt) that has filled the central void.

For comb plates SF 407:b:2 and SF 453:f, each plate has one missing rivet, allowing us to measure the diameters of the rivet holes from the SEM images. Both were 2.0 mm (fig. 5). This observation will be further discussed below, together with the analysis of the antler plates.

For comb fragment 268:1:251 from the Götes mack site, the SEM analysis shows that the copper rivet consists of solid metal with small amounts of corrosion (fig. 6). The better preservation of this object is likely related to it being more recently excavated – in 2014 – than the comb frag...
Fig. 4. Top: An antler tooth plate (SF 407:b:1), excavated from the Trekanten site. The white scale bar is 5 cm. Photo: Anders Söderberg. Bottom: SEM image of one of the corroded rivets. The yellow circle indicates two circular layers of corroded copper, consistent with the rivet being made from strip-drawn wire. SEM image by Sebastian Wärmländer.

Fig. 5. Top: Two antler tooth plates (SF 407:b:2 and SF 453:f) for single composite combs, excavated from the block Trekanten in central Sigtuna. The white scale bar is 3 cm. Bottom: SEM image of the rivet hole from comb fragment SF 407:b:2, with a diameter of 2.0 mm. Images by Sebastian Wärmländer.
ments excavated from the Trekanten site in 1925. The storage conditions for the Trekanten finds were apparently not ideal, as often was the case for material from the early Sigtuna excavations. The top view SEM image of the rivet effectively shows it in transverse cross-section: it is clearly circular and solid. Thus, this rivet is made from copper wire produced by a technique such as casting, hammering or proper wire-drawing (Ros 1990). The scratches in the image originate from the rivet ends being cleaned with a Dremel rotary tool. The rivet composition is approximately 93.2% Cu, 5.6% Zn, 0.6% Pb, and 0.6% Sn. The other comb fragment from the Götes mack site, 181:3205:247 (no image shown), displays a rivet with a similar solid cross-section and a composition of approximately 99.5% Cu and 0.5% Pb. The use of copper-zink alloys (i.e., brass) is not surprising, as brass was commonly used in the Viking and Medieval periods (Saage & Wärmländer 2018; Jouttijärvi 2002, p. 39) and traded from the European continent as a standardized commodity (cf. Sindbæk 2001). The rather pure copper with a small amount of lead found in the rivet from comb fragment 181:3205:247, might originate from recycled brass: during each re-smelting cycle some zinc will evaporate, while any lead present will remain. This would not necessarily be a disadvantage, as it would result in a very Cu-rich alloy that would be softer and easier to draw.

The two antler plates

The two studied antler plates, SF 697:h and SF 449:m (fig. 7), were found during the 1925 Trekanten excavation in direct connection with the bronzesmith’s workshop (Floderus 1928). With reference to the above discussion on the contexts and dating of the comb fragments, the antler plates can roughly be dated to the late 11th or the 12th c. Their dimensions are 5.0 x 4.1 x 0.5 cm (SF 697:h) and 4.1 x 3.7 x 0.3 cm (SF 449:m). Floderus (1928) described the material as elk antler, which appears to be correct. SEM-EDS analysis revealed large amounts of calcium and phosphorus in the plates, which is expected from a bone/bioapatite material. The microstructures of the plates (figs. 7 and 8) are compatible with antler, and especially that of elk, where the spongy tissue is denser than in antler of e.g. red deer and reindeer (Ashby 2013; Karlsson 2016). The plate dimensions also indicate a large animal such as elk. Determining species from morphological features is however difficult, and biomolecular analysis of DNA or proteins from the material can often provide a more reliable species identification (Ashby 2013; Ashby et al. 2015; Smirnova 2005; von Holstein et al. 2014).

SEM analysis of the two plates

SEM analysis identified metal particles consisting mainly of copper and lead around some of the holes in the plates, at both the front and back sides (fig. 8). Because these particles are very small (around 1–10 micrometres) and also corroded (CuS and PbO appear to have formed), it is in
Fig. 7. The two studied antler plates, SF 697:h and SF 449:m, excavated from the bronzesmith’s workshop in the block Trekanten in central Sigtuna. The white scale bars are 5 cm. Photos: Sebastian Wärmländer.

Fig. 8. SEM images of holes in the studied antler plates. A) Hole from plate SF 449:m, front side. Note the metal residue in the bottom left corner. B) Hole from plate SF 697:h, front side. Note the false start of the hole (yellow rectangle), which proves that the hole was drilled. C) Hole from plate SF 697:h, back side. Note the large metal particle in the bottom right corner. D) Close-up view of the metal particle shown in (C). E and F) SEM-EDS maps showing the metal particle to contain large amounts of copper and smaller amounts of zinc – only slightly above the noise level. The diameters of the holes shown in (A-C) are all 2.0 mm. Images by Sebastian Wärmländer.
most cases not possible to elucidate from which original alloy compositions the residue particles originate. One exception is a relatively large particle (50 x 32 micrometres) next to a hole on plate SF 697:h (figs. 8C and 8D). This residue particle consists of brass with around 92% Cu and 8% Zn (figs. 8E and 8F). Some sulphur was also observed in the particle, indicating that it is at least partially corroded. Hence, as zinc typically corrodes before copper, the original zinc content may have been somewhat above 8%. The holes are perfectly circular with uniform diameters of 2.0 mm (figs. 7 and 8). The false start shown in fig. 8B is evidence that the holes were drilled. Because drills during the Viking Age and Medieval Period typically were made from iron or steel (Ohlhaver 1939; Petersen 1951) – we are not aware of any evidence for the use of bronze or brass drills during these time periods – we conclude that the copper and lead residue observed around the holes does not originate from when the holes were drilled.

The antler plates as possible wire-making tools

The holes in the antler plates, and the observed metal residue around them, are likely related to how the plates were used. In his 1928 paper, Floderus proposed that the plates were used for wire-drawing. If so, the copper residue suggests drawing of copper-alloy wire. The plates’ holes are however cylindrical and of uniform size, i.e., 2.0 mm wide (figs. 7 and 8 A–C). As discussed above, this indicates that the plates were not used for drawing solid wire, as plates used for that purpose should have conical holes, typically of different sizes (Newbury & Notis 2004; Oddy 1977). It is furthermore unclear if antler is a strong enough material to allow drawing of solid copper-alloy wire. Antler plates may however be sufficiently strong to allow production of copper-alloy wire by the strip-drawing method (Oddy 1977; Williams 1924).

Although the Saami people of northern Scandinavia have a tradition of using plates of reindeer antler to draw tin wire (Zachrisson 1970), it is generally uncommon to find tools of bone or antler in metal workshops (Grassi 2016; MacGregor 1985, p. 171 fig. 89; Vuković-Bogdanović & Bogdanović 2016). Yet, there are a number of circumstances to support the idea that the perforated antler plates might have been involved in producing strip-drawn copper-alloy wire, possibly used to manufacture the hollow rivets found in some of the studied comb fragments (figs. 3 and 4). The antler plates’ holes all have diameters of 2 mm, and they display residue of copper and zinc (fig. 8). The comb rivets are made from copper and zinc, and the rivet holes are 2 mm across (fig. 5). The two antler plates were found together with various objects, including a strip of lead, finished and unfinished antler combs, glass beads, pottery sherds, and pieces of leather (Floderus 1928). The presence of combs together with the antler plates may be a coincidence, and the general mixing of the waste from the bronzesmith’s and the combmaker’s workshops observed during the excavation is perhaps not unexpected, given that the two workshops were located a mere 13 meters apart (Floderus 1928). On the other hand, if the combmaker indeed obtained the rivets for his combs from the bronzesmith, it would make sense to have the two workshops situated next to each other (Croix et al. 2019). It might even have been the bronze smith’s task to attach the rivets to the combs, and some craftsmen could have worked in both workshops (cf. Hansen 2015).

While these circumstances may appear convincing, they do not constitute proper proof. It is quite possible that the antler plates had a totally different purpose. Or they might have been used as expedient tools when making comb rivets, but not necessarily as draw plates. An alternative function could be as support plates when heading the rivets. We do not know the steps involved when the rivets were attached and secured to the combs, but we might speculate that a piece of copper wire was inserted into the rivet hole, and then both ends were hammered at to create the rivet heads. In such a scenario, a thin support plate with a hole of the same dimension as the comb’s rivet hole would have been required when the first end was headed, to support the wire end protruding from the other side of the comb (fig. 9). Thus, the antler plates could have functioned similar to how nail headers are used in nail production (Edberg 2013; Ryzewski & Gordon 2008; Wells 1998). Medieval smiths and metal-workers were clearly familiar with the concept of nail-heading (and rivet-heading), as from the Viking
Age onwards iron nail headers were common tools in Scandinavian smithies (Ohlhaver 1939; Petersen 1951; Westphalen 2002) including those in Sigtuna (Edberg 2013). But this possible use of the antler plates is just a speculation, as we do not know the procedures nor the tools used for attaching the rivets to the combs.

The above discussion illustrates the problem of attributing a unique function to a tool that consists of a simple plate with seemingly randomly distributed holes of equal size. It also illustrates the problem of identifying the tools used for strip-drawing metal wire, as any perforated object likely could be used. Overall, we believe that the best current interpretation of the two perforated antler plates is that they were used as strip-drawing tools. Even though this tentative conclusion is open for discussion, our results at least indicate that tools made from soft materials such as bone, antler, and wood might have been used when strip-drawing (and possibly roll-drawing) metal wire. Studies using experimental archaeology, and ideally in combination with SEM (Özsén & Willer 2016) or/and 3D analysis (Nieß et al. 2016; Sholts et al. 2012), should be able to investigate the material properties required of the drawing tools when producing wire of metals and alloys with different hardness and ductility (e.g., tin/ pewter, gold, silver, copper-alloys, and iron/steel).

**Conclusions**

Our analysis of 11th–12th c. composite antler combs from Sigtuna confirms the suggestion by Hansen (2005), Galloway (1990), Ros (1990), and Stjerna (1998) that copper rivets in early Medieval com-

![Fig. 9. One possible use for the perforated antler plates. In a scenario where a rivet (light grey) is attached to a composite comb by inserting a piece of wire into the rivet hole and then heading it from both sides, a perforated plate will be needed to support the protruding wire end (at the bottom) when the opposite (upper) end is being headed. Image by Sebastian Wärmländer.](image-url)posite combs were sometimes produced by hollow strip-drawn wire (figs. 3 and 4). This proves wrong Duczko’s (1985) statement that objects containing non-solid wire should be pre-Viking Age. Some comb rivets were however found to be made from solid metal wire (fig. 6), which was produced either by hammering, casting or solid wiredrawing (Ros 1990). Further research is required to clarify the different wire-making techniques used in Medieval Sigtuna, as well as when the strip-drawing method eventually was discontinued, in Scandinavia and elsewhere.

The two perforated antler plates suggested by Floderus (1928) to be draw-plates were found to contain traces of copper next to their holes (fig. 8). Although they were not likely used to draw solid wire, the plates may have been used to produce hollow copper-alloy wire by strip-drawing. A possible production connection between the antler plates and the composite combs is supported by the hollow comb rivets arguably being made from strip-drawn wire, by the close proximity of the bronzesmith’s and the combmaker’s workshops, and the identical dimensions of the rivet holes of the studied combs and the holes of the two antler plates (figs. 5, 7 and 8). However, other uses for the perforated plates are also possible, such as support plates when heading rivets (fig. 9).

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References
Davidan, O., 1982. Om hantverkets utveckling i Staraja Ladoga. Fornvännen 77.
Saage, R. & Wärmländer, S. K. T. S., 2018. Metal resi-


