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Fastenings and Caulking: overview of archaeological evidence

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1 Introduction

The Sutton Hoo Ship's Company was established in 2016 with a goal of building a full-scale replica of the Sutton Hoo ship. The project follows the rules of experimental archaeology in shipbuilding (Coates et al., 1995; Bischoff et al., 2014; McGrail, 2016), and aims to maximise accuracy with available resources and knowledge. The first phase involved a review of archaeological data concerning the ship's dimensions, and creation of a digital reconstruction that allowed refinement of plans from all excavations of Mound 1, as well as assessment of propulsion and hydrodynamics (Tanner et al., 2020).

The project has recently entered the shipbuilding process and further aspects are being investigated. Some of the details that require additional assessment are fastenings and caulking. This report provides a review of archaeological evidence concerning materials used for fastenings and caulking (from primary and secondary sources), as well as common practices in experimental archaeology relating to shipbuilding process. The aim is to produce a set of recommendations and explore possibilities concerning further experimental trials of different materials.

2 Background

The famous ship burial (Fig. 1) is one the most prominent finds of the Early Medieval period. It provides a unique and intricate window into craftsmanship and structures of the Anglo-Saxon society. A range of preserved finds, as well as the imprint of the vessel itself demonstrate seafaring capabilities and a wide network of connections. Some objects originate from Syria (e.g. 'Coptic' bowl) (Bintley, 2011), and metalwork was inlaid with materials imported from India or Sri Lanka (Riccardi et al., 2019).

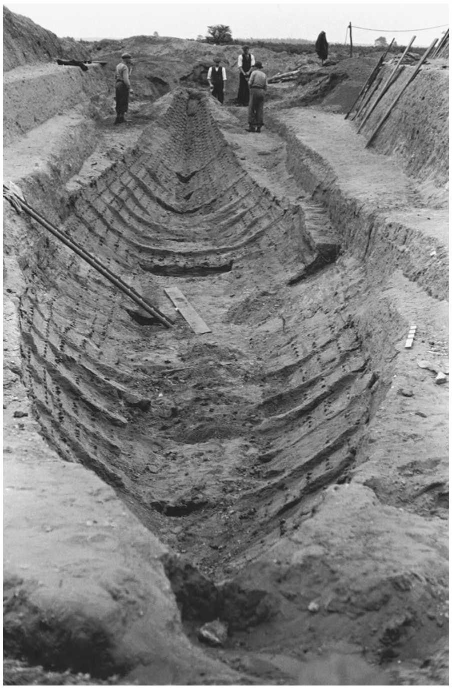

Figure 1 *Excavation of the Sutton Hoo ship burial in Mound 1 (Lack, 1939; Copyright: The Trustees of the British Museum).*

The Sutton Hoo ship burial was discovered in 1939, during the second season of excavations commissioned by Edith Pretty, and directed by Basil Brown and Charles Philips. The site was revisited in the 1960s by Bruce Mitford (Bruce-Mitford, 1975), and in the 1980s by Martin Carver, who also directed excavations of another cemetery during the construction of the visitor centre (Carver, 2005).
The ship was located in an Early Anglo-Saxon cemetery consisting of 17 mounds. It was an elite burial ground that included two ship burials (Mound 1 and Mound 2), and a burial with horse remains in Mound 17 (Evans, 2005). Mound 2 was looted, and ships remains were heavily disturbed. The acidic soils of Suffolk caused the complete decomposition of the organic components of the Mound 1 ship but concreted rivets, preserved in situ, provided a relatively good record of the vessel that was buried under the mound in the early 7th century. The ship was 26.33m long, and measured 4.39 m amidships (Tanner et al., 2020:23). It was a rowing vessel, although its sailing capabilities were discussed and tested previously (Gifford & Gifford, 1996). Based on the contemporary evidence it was most likely made of oak.

2.1 Saxon shipbuilding and clinker tradition

Comparative evidence of Early Anglo-Saxon boat finds includes the aforementioned Sutton Hoo Mound 2, Snape boat burial (albeit heavily disturbed), and several vessels with limited documentation or remains lost after excavation: remains from Caister-by-Norwich, Ashby Dell and Catfield (Goodburn, 1986; Pearson et al., 1993). The Graveney boat is the only Anglo-Saxon find with good preservation of organic material. In addition, there is evidence of boat fragments from early Saxon burials in Kent, and it includes in sites such as Sarre, Thorne Farm and Half Mile Ride (Brookes, 2007). Sarre is a particularly wealthy example, with evidence of imported goods in elite burials (Behr, 2000:45), as well as a woodworking tool (Goodman, 1965, in: Long, 2008:41). Later finds are known from York and London waterfront, where fragments of ships were reused as elements of wooden constructions. Some settlements, such as Hamwic and Coppergate, York (Ottaway, 1992), produced evidence of ship-repairs or breakage in form of iron rivets.
The Sutton Hoo ship belonged to a widespread North European shipbuilding tradition, and its closest and well-preserved parallel was found in Denmark, where remains of three boats were recovered from the Nydam bog. The second Nydam vessel (Fig.2), made of oak, was the most complete out of the finds. It was dated dendrochronologically to the early 4th century CE, and measured c. 23m (Rieck, 2013b: 21, 34). The vessel was rowed, and it represents an early example of clinker construction. Associated evidence indicates that the boats were possible spoils of war, or a ritual deposition that occurred in few stages. Several other boat fragments were also found in the region (Cameron, 1982; Bill, 2019:311). Other examples of vessels that date closely to the Sutton Hoo find include burial complexes from the Vendel period (Vendel, Valsgärde) (Bill, 2018; Hesselbäck, 2020), a ship burial from Solleveld in the Netherlands (Ovemeer, 2006:70), two ship burials from Rogaland: Storghaug and Gronhaug (Bonde & Stylegar, 2016), and two ships from Salme (Peets et al., 2010), as well as Kvalsund boats from Sweden (Nordeide et al. 2020).

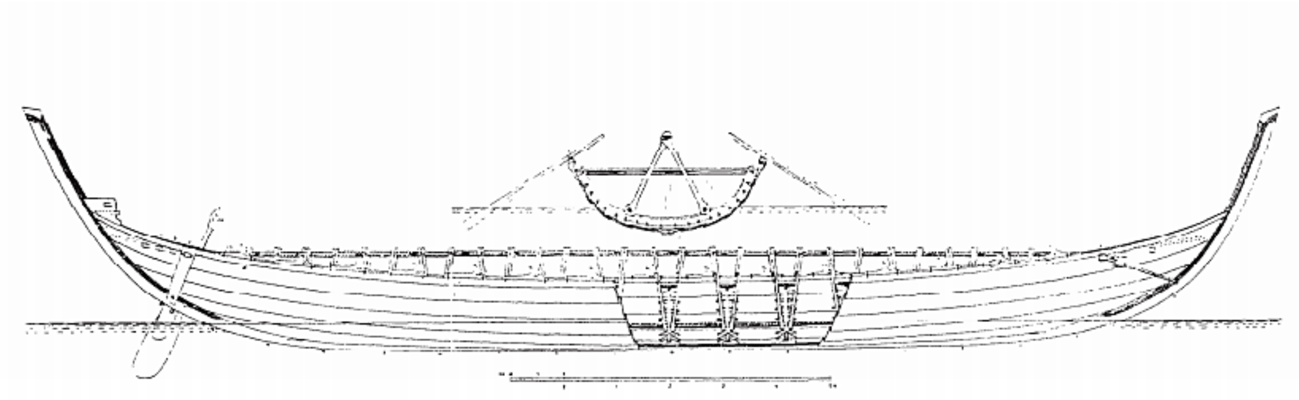

Figure 2 *Reconstruction drawings (elevation and midship cross-section) of Nydam 2 (Åkerlund 1963, in: Crumlin-Pedersen 1990:109).*

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The Nordic tradition of clinker shipbuilding persisted during the Middle Ages as the main construction technique of Northern Europe, but it was later replaced by carvels (Smith, 2009). In Scandinavia, clinker vessels were still built commercially in the 19th century, so practices in archaeological reconstruction draw heavily from traditional shipbuilding (Eriksson, 2010). The characteristic features include shell-based construction of overlapping strakes joined by iron rivets. Frames are inserted into the hull, and their shape is fashioned after the inboard profiles of the strakes. Shell-based construction means that the vessel's shape is determined by planking rather than frames. Such method produces strong and flexible vessels, although their construction was expensive both in terms of time and materials needed. As this tradition was used widely in the first millennium CE, the comparative evidence can be drawn from multiple case studies, which include famous Viking Age remains such as Oseberg and Gokstad ship burials, and five Skuldelev finds.

3 Fastenings and caulking in clinker shipbuilding

Caulking and fastenings are crucial elements of shipbuilding process as they join individual structural elements of a vessel. The use of fastenings allows a wide range of hull construction and has impact on its strength and flexibility- which plays crucial role in relation to environmental conditions of seafaring. Caulking ensures watertightness between vessel joints which include: stem and stern post and their attachment to the keel; placement of individual strakes (starting from garboard and ending with the gunnel); stringers and individual plank connections within the strakes (scarph joints); and internal elements that reinforce the transverse strength of the vessel.

3.1 Caulking

Aside from acting as a sealant in watercraft's plank connections and joints, caulking aids preservation of wood (Findlay, 1943; Källbom, 2015:78; White & Stern, 2017:339). In archaeological literature, 'caulking' and 'luting' are sometimes distinguished, with the former referring to the application of material prior to the assembly, and the latter to its addition when the plank is fastened to the strake (Indruszewski, 2003: 217). However, both methods are used in experimental shipbuilding and will be regarded here as synonymous. The process of shipbuilding, including caulking, constitutes an element of intangible heritage and there are no early medieval depictions of caulking process. Thus, the construction sequence described below is based on observations from resources provided by experimental centres from Denmark and Norway. Those are a combination of practical knowledge, ethnographic evidence from Scandinavia (Dhoop & Olaberria, 2015) and archaeological remains (such as tools (Appendix 2), and toolmarks).

Caulking can be applied prior to the insertion of a new plank (Fig.3). Fibrous material is fixed to the tarred surface of the scarph joint, and along the seamline. Then, the plank is clamped to the strake. Alternatively, the seam caulk is inserted to a newly clamped plank, with the aid of wooden wedges (Fig.4). This process, however, requires more skill as there is a risk of driving caulk into the plank rather than the seam. Such mistake could destroy the plank's surface and deteriorate its resistance to rotting (van Gaasbeek, 1919: 82). In either situation it is easier to insert a loosely spun material. In addition, a small amount of caulking can be wrapped around rivets when those are inserted (Fig.5).

Figure 3 *Insertion of a caulked plank to the hull strake (Draken Harald Hårfagre, 2014).*

Figure 4 *Insertion of caulking into seams of clamped strakes (Ribe VikingeCenter, 2019).*

Figure 5 *Fastening of a repair plank to the hull with the use of copper rivet and caulking material (Vikingeskibmuseet i Roskilde, 2020).*

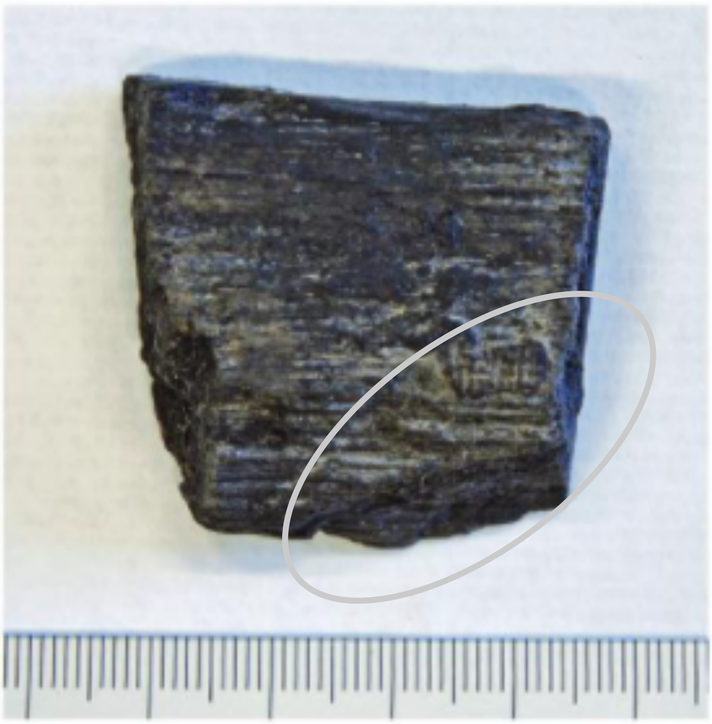

Figure 6 *Nydam 2, plank fragment (5780). Caulking material preserved in the bottom right corner (circled) (Möller-Wiering, 2011:86).*

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3.2 Caulking fibre

Caulking usually is made of two elements: a fibrous material paired with resinous substance. Since the organic ship elements from Sutton Hoo were not preserved in the acidic sand, and there are no close parallels from early Anglo-Saxon England, there is a necessity to draw from a wider archaeological record. Only a few Anglo-Saxon remains had caulking preserved, all dated to the Late Saxon period. One such find is the Graveney boat, a 10th century vessel, and most likely a local cargo ship (Fenwick, 1972). It was caulked with tarred wool or cattle hair - there are conflicting accounts in archaeological literature (Evans & Fenwick, 1971:93; McGrail, 1998). Another find is a boat fragment from the river Usk near Newport, also dated to the 10th century. It was caulked with a mixture of wool and animal hair (either cattle or horse) (Hutchinson, 1984). The fibre was not spun; a tangled mass of hair was held together by tar. Two other fragments of late Anglo-Saxon ships were caulked with plant material. The Nydam ship was caulked with fabric remains, and specifically with woven textile fragments (Möller-Wiering, 2011) (Fig. 6). Those ranged from simple tabby weaves to more valuable diamond twills, and all were most likely recycled scraps of fabric (Grömer, 2017). The wool thickness varied from coarse to fine, so it was not a relevant feature in the selection of material for caulking. Fabric strips were also used in Halsnøy boat (Jørgensen & Moe, 2020), and tarred scraps of fabric were found in a container from Hedeby (Hägg, 1984:11).

Traditionally two main variations in early clinker shipbuilding are recognised: *Scandinavian* -characterised by woollen/hair caulking and iron rivets, and *Slavic*- with moss caulking and wooden treenails. However, two late Anglo-Saxon finds, (e.g. New Fresh Wharf (Goodburn, 1986)) incorporate *Slavic* elements, while some finds from Poland, such as Puck 2 (Crumlin-Pedersen, 2009:239) were caulked with animal hair, and ship remains from Truso were fastened with iron rivets (Jagodzinski, 2017) (although a separate, Eastern Baltic tradition is sometimes distinguished (Kontny, 2019)). Such outliers reflect that the use of methods and materials is not limited to discrete regions, and various shipbuilding methods were encountered within individual sites around the Baltic and the North Sea. Furthermore, watercrafts are inherently mobile, and it cannot be assumed that findspots signify their provenance.

Watercraft	Deposition date (CE)	Length	Strakes per side	Hull Fastenings	Caulking	Resin
Halsnøy	2nd/3rd c AD	c. 17.5m	N/A	S	Textile	I, U
Nydam 2	c. 350	c 23m	6	R	Textile	I, *P**
Gredstedbro	c. 7th c.	c. 20	8	R	Animal	N/A, *I**
Sutton Hoo 1	c. 625	26.33m	9	R	N/A	N/A
Kvalsund 2	c. 800	c. 18m	8	R	Animal	N/A
Valsgärde 14	early 9th c.	c. 12m	6	R	Animal, *Wool**	N/A
Oseberg	c. 834	21.5 m	6	R	Wool, Fabric	I, U
Graveney	10th c.	c. 14 m	7	T, R	Cattle	I, U
River Usk	c. 950	N/A	N/A	R	Wool, Cattle/Horse	I, U
Skuldelev 2	c 1042	c. 30 m	12	R	Wool, Fabric	I, U

Table 1 *Examples of caulking in clinker ships (Iron Age- Medieval). S- sewn, R- iron rivets, T – treenails, I – tar identified, P- pine, U -type unspecified, N/A- not mentioned in sources, * - based on objects from site, but unconfirmed by bibliography. Sources: Walton, 1989; Hutchinson, 1994; Crumlin- Pedersen, 1997; McGrail, 1998; Croome, 2005; Wickler, 2019; Jorgensen & Moe, 2020.*

Wool and animal hair seem to be the prevalent materials used in caulking (Table 1). Moss caulking does not occur in the evidence from the North Sea region in the early Anglo-Saxon period. Its appearance in later examples may be linked to growing popularity of moss caulking in Frisia. This trend persists to the Middle Ages, when Dutch shipbuilders frequently employed this technique (Cappers et al., 1997). Oakum, caulking made from flax or hemp, was widely used in northern Europe during the Roman period (Ryder, 1994), and in shipbuilding of the early modern period (Gearey et al., 2005; Gibson, 2006). However, there is no direct evidence of the use of flax or hemp in Early Medieval caulking.

Tar

Another significant element of caulking material is tar, but its archaeological analysis is limited (Table 1). It would often be mixed with fats for easiness of application (Evans, 1994), and in case of dry fats, solidification of solution. Linseed oil is a common choice in traditional shipbuilding (Rawson et al., 2014). A mixture of tar, ochre and linseed oil was found on a Skuldelev find (Hennius et al, 2007:602). Bitumen form the Sutton Hoo Mound 1 burial was initially interpreted as remains from the ship's caulking, but scientific analysis of tar and the find's contexts suggest that was unlikely (Burger et al., 2017). The bitumen was imported from Syria and was one of the burial's rich grave goods. Both Graveney and River Usk finds had tar remains preserved but those were not analysed. The publication on finds from Nydam also does not specify what type of tar was used in Nydam 2, but Nydam 1 was caulked with tallow (likely sheep) and birch tar, whereas Nydam 3 was caulked with pine resin and animal or plant grease (Bockius, 2013:269). As woollen caulks from Nydam 2 and 3 were tested together and no variation was mentioned (Bockius, 2013:269) it is likely that both were covered in the same material.

3.3 Fastenings

Rivets join hull strakes together and allow creation of the characteristic clinker overlap. Metal fastenings can also join garboard stakes to the keel, gunwales to the shell and individual planks within the strakes. In the Sutton Hoo ship, frames were joined to the ninth strake of the hull with iron bolts. Additionally, some elements of joinery used organic material, most likely treenails, although no direct evidence survives to confirm it. According to the survey records concerning the Ashby Dell vessel, the frames were lashed to the hull. However, original plans and ship remains did not survive, so it cannot be revisited (Bruce-Mitford, 1975:426-8). In Nydam ship, the frames were lashed to the plank cleats with the use of lime bast (Rieck, 2013a). Kvalsund 2 also had its frames lashed (Ejstrud & Maarleveld, 2008:78). In turn, the ship from Gredstedbro and from Kvalsund 1 had their frames treenailed (ibid.). The Graveney boat is an unusual example because the planks had iron rivets driven through wooden pegs. Comparative evidence does not provide conclusive decision. Similar issue is encountered when analysing the existence of caulking grooves in planks. Nydam strakes did not have those (Rieck, 2013a). All three shipwrecks from Hedeby (1-3) contain strakes with grooves, while plank fragments from Schleswig show variations in evidence, and some specimens do not have plank grooves (Crumlin-Pedersen, 1997). The New Fresh Wharf vessel fragment did not have a groove (Mardsen, 1994:142). It appears that both methods were used parallelly, although the earliest known example does not have caulking grooves, which may suggest a later introduction. Unfortunately, the intermediary find, Gredstedbro ship, does not have its strakes preserved.

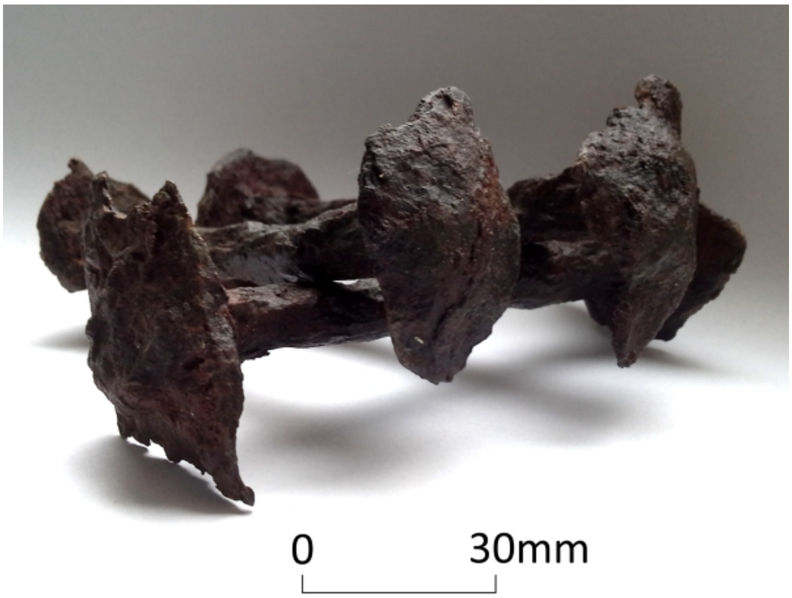

Figure 7 *An example of Early Medieval ship rivets from Thorne Farm, Minster (Thanet Archaeological Society, 2014).*

Most of the fastening process will focus on strake rivets. When initial planks are fitted and held to the hull with clamps, holes for rivets are drilled. Fastenings are hammered through the planks from the outboard. Then, roves are hammered down through the inboard rivet ends, and their excess length is cut off. Clinking, the process of hammering of the inboard rivet end, begins. It secures the cut end by flattening of its surface and formation of a second rove head. It is often done with a help of another person hammering the outboard end of the vessel. Copper nails are frequently used instead of iron in modern replicas. Iron oxidisation causes substantial degradation of adjacent timbers, which is known as *iron sickness*. In contrast, copper can withstand corrosion and has high impact resistance (Akande et al., 2015). For a long time it was intended the Sutton Hoo ship reconstruction project should use copper nails (Whitewright, pers. comms., 2020), with the exception of iron gunwale spikes. A decision to use iron fastenings throughout was made August 2021. This was on the grounds of authenticity, accepting the risk of reduced longevity.

4 Industries and environmental data

4.1 Caulking

Cordage is closely linked to textile production industries and animal husbandry. Flax was one of the most universal textiles in the period. Linen textile remains are known from burials contexts in all regions, including Sutton Hoo (e.g. Mound 14 (Evans, 2005)). Pollen analysis results show that hemp was cultivated throughout the Early Middle Ages (Godwin, 1967) and its popularity grew in the Late Saxon period (Schofield & Waller, 2005), although surviving hemp textiles are limited (Walton Rogers,2007:14). Both the environmental and textile data indicate that hemp was most widely cultivated in East Anglia (Godwin, 1967; Hooke, 1989). However, it is possible that hemp is underrepresented because its pollen profile is very similar to hops (Edwards & Whittington,1990:64).

Animal remains preserve better in archaeological records than plant remains. One of examples of animal husbandry in small-scale economy is West Stow village. There ovicaprid remains, followed by cattle, were the most numerous in the assemblage (Crabtree, 1989:208). Wool, alongside linen, was a common fabric, and large quantities of textile production remains attest to its significance in local economies (Rogers, 2018). Iron Age sheep breeds had predominantly coarse and medium wool (related to Orkney and St Kilda types) but breeds with finer wool were introduced to Britain in the Roman period (Walton Rogers, 2007:11-3). The analysis of medieval cattle hair caulking revealed that majority represented 'primitive' breeds, with a small proportion of Highland cattle (Ryder, 1998). Some of British breeds with 'primitive' cattle features are White Park and Kerry cattle (Upadhyay et al., 2017) but other Northern European breeds are also closely related (MacHugh et al. 1999). The appearance of root ends in Medieval samples suggests that hair was extracted during leather processing (Ryder, 1998:68).

Tar is produced by destructive process (controlled dry distillation of tree resin) in anoxic conditions. The controlled firing environment must be supervised for several days. The end products are water, tar, pitch (higher concentration of resin), and its by-product is charcoal. There is no evidence of tar production from Anglo-Saxon Britain, so a wider perspective is needed to shed light on the practices. In Scandinavia the growing scale of tar production between the Iron Age and the Viking period is reflected by pit remains (Hjulström et al., 2006; Hennius, 2018). Late Iron Age and Vendel period production was located near rural settlement sites, likely for the needs of individual households or small settlement units (Hjulström et al., 2008:66-76). By the Viking period, the production involved large-scale hinterland activities (construction of funnel pits), and woodland management (procurement of timber) (Hennius, 2018). Archaeological remains are found in vicinity of pine forests.

In Finland, where traditional large-scale production persisted to the 20th century (Fig. 8), pits filled with pine blocks were covered with moss and turf, then fuel was set around the structure and set on fire. This protective layer would prevent fatwood from aeration (Kurt et al., 2008:617) and rapid burning. Tar produced for the Sea Stallion in Roskilde museum was produced in Finland with the use of such traditional techniques (Fig. 8).

Figure 8 *Tar production in Finland in 1910 (left), and at the time of Sea Stallion construction (Roskilde museum project, 2000- 2004) (Finnish Heritage Agency; Vikingeskibmuseet i Roskilde, 2015).*

Despite lack of Anglo-Saxon evidence of production, there are a few finds of bitumen from the period. A recent study of tar remains from Ealy Anglo-Saxon cemeteries at Cherry Hinton, Cambridge and Ringlemere Farm, Kent revealed that in both instances tar was extracted from birch (Stace et al., 2020). In addition, both pots contained residues of animal fat. The small amount and find contexts suggest medicinal use. Pine tar was found in Early Medieval York and comes from an Anglo-Scandinavian settlement site (Evershed et al., 1985). It is possible that evidence concerning small batch production has been overlooked. Some archaeological reports mention pits with deposits of dark sticky substances at the bottom of sloping of funnel-shaped pits (e.g. Dransfield et al., 2015:121). However, those could also relate to other production practices such as pottery firing or crop processing, and identification would require analysis of residues.

Tar was most likely used as a solution of tree-resin and a fatty substance (White & Stern, 2017), as in case of linseed oil in wood conservation (Łucejko et al., 2018). A range of products used in the past include animal fats, e.g. tallow residues were found in Nydam, Early Saxon burial finds, and seal fat was occasionally used in the Viking period (Ogilvie eat al., 2009:8). The Hedeby ship remains were covered in tar with ochre and linseed oil, and beeswax was a common component in caulking of Roman ships (Colombini et al., 2003).

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4.2 Fastenings

The original choice of copper for the rivet material in Sutton Hoo reconstruction was justifiable based on production cost, the availability of raw materials, and concerns regarding preservation of the ship timbers. Furthermore, the composition of archaeological rivet material is poorly understood. Steel rivets were used as fastenings of Roar Ege, and its wood was damaged by iron relatively quickly (Vikingeskibmuseet i Roskilde, 2018). It was suggested that iron with different composition could facilitate better preservation, but such process would require sourcing of bog iron (Sørensen & Dael, 2020). The use of copper should not have had significant impact on the vessel, and this practice is also applied in Roskilde. The later decision to use iron was based on accepting the risk of reduced longevity, and on hoping that more suitable iron could be sourced at reasonable cost, as well as the wish to be more authentic.

One matter that should be taken into consideration if choosing between these two metals is their difference in density. Copper is 14% denser than iron, so if the same volume of material is used, the weight of the fastenings will increase accordingly. For the Sutton Hoo ship this difference would be of the order of 100kg. This is small considering the overall weight of the vessel, and it could be factored into the total weight of the crew, cargo, or the ship's ballast.

Further discussion concerning the materials used for frame fastenings (and treenailing or lashing) is beyond the scope of this report, as it has implications for the structural form of the vessel. Archaeological evidence remains inconclusive, and environmental data indicates availability of materials for both solutions. A range of tree species suitable for treenails would be easily accessible, while lashing could be made from lime bast- made of a species used throughout the period (Helliwell, 1989), e.g. in shield manufacture (Härke, 1992; Comey, 2013:109).

5 Discussion: a Saxon boat in a modern world

The choice of materials and construction methods ought to mediate archaeological context, lack of primary evidence, and limitations in availability of materials. Caulking seems to reflect regional preferences and cultural choices, albeit those changed over time. Both flax and hemp were grown during the period, and flax was widely used in textile production. It was used in shipbuilding of later and earlier periods, and its effectiveness as a caulking material is undeniable. However, there is no early medieval evidence that supports its use in shipbuilding. Late Saxon examples include moss and animal hair- their use is also known from other regions within Northern Europe, and it appears that there was a shift from wool to hair in the Middle Ages (Möller-Wiering, 2002). It is possible that moss caulking was introduced to Britain in the Late Saxon period, as no examples closely dated to the Sutton Hoo were identified. However, negative evidence is not conclusive, as other uses of those materials, just like in case of oakum, are found in archaeological record. The closest parallel, Nydam 2, used scraps of woollen fabric. It was widely available in the period and allowed reuse of worn textile fragments. The persistence of this practice is supported by late Viking period evidence, e.g. a bucket from Hedeby, and caulking fragments from Oseberg (Walton, 1989:335). Nydam find was not a unique occurrence. However, other reports do not always distinguish whether recycled fabrics or loosely spun wool was used, or if it was a mixture of both. Procurement of substantial quantities of recycled woollen fabric for the project might pose a bigger challenge than a purchase of unspun wool. The use of wool and animal hair mixture cannot be ruled out. However, sustainable sources of large quantities of cattle and horsehair might prove both costly and difficult to find. In contrast, plant materials for oakum were known in the period, and despite lack of primary examples, those would be a relatively low-cost substitute. Its use would also be a nod to the regional heritage, and East Anglian production of hemp for ships in the early modern period.

Tar is more elusive. The only analysed finds from Britain include burial contexts and suggest their use for personal needs. It had application in medicine, coating of pots and vessels, adhesive and for maintenance of personal equipment or weaponry. The use of tar as antiseptic also persist to these days in animal care. Despite the use of birch in two finds, it is uncertain what species would have been used for shipbuilding. Both finds contained small quantities, and the small-scale double pot production has been known since prehistoric times (Kozowyk et al., 2020). Birch and pine were used throughout the period in woodwork, so they were sourced as raw materials (Hooke, 2010; Hinton, 2011:424). Two nearly contemporaneous vessels from Nydam used different types of tar. The availability of large quantities of resin might be a deciding factor in its choice, as

archaeological evidence remains ambiguous. Based on the tar usage from the Skuldelev 2 reconstruction, a 30 m ship (without sail but with sail rigging) would need about 500 litres of tar. Large batches of pine tar might be more accessible, although birch tar (produced primarily for medicinal purposes) is also available. Early Medieval evidence from England would prioritise birch, while the choice of pine would be based on the wider North European shipbuilding tradition and later Anglo-Scandinavian finds.
Linseed oil is used commonly in modern-day natural tar compounds, and there is evidence that it was used in the Viking Age. Another possibility is animal fat or beeswax. The effectiveness of fatty substances in ship preservation was tested previously although beeswax was not included in the project (Miljøstyrelsen,2003), and the exact difference in application and durability of those solutions in shipbuilding is unknown.

6 Conclusion

Due to the state of preservation of the Sutton Hoo ship, comparative evidence needs to be used in order to provide rationale for choice of materials. This report provides a range of archaeological evidence as well as environmental background that can facilitate such decisions. It represents the current state of knowledge, so it could be refined by further analysis of existing evidence or new finds.
Based on the archaeological record and availability of materials the recommended caulking material is wool, although other materials such as hemp and animal hair were available during the period. There is no direct evidence for large-scale tar production in Britain, so an area of ambiguity remains in this regard. However, both birch and pine sources were available throughout the period and used in shipbuilding in the first millennium CE. Pine tar would be a sensible choice, mainly due to its availability. The addition of linseed oil is often recommended, although tar mixed with beeswax was used in weaponry from Nydam, and tallow in ships. Further experimentation with beeswax and animal fat could provide insightful results to inform a final decision.
Fastenings are already selected, and the choice of iron is accurate and represents structural elements preserved in archaeological record, while the use of trenails for frame fastening is one of two possible scenarios based on the archaeological evidence.

7 History

Status	Date	Author	Details of change
Issue 1.0	5/6/21	Kasandra Boguslawska	Offered as a report, based on a dissertation for elsewhere. Accepted as was.
Issue 2.0	29/9/21	Kasandra Boguslawska	Converted to the usual SHSC format. Peer reviewed, and modified by Joe Startin in section 3.3 and 4.2 to reflect the decision to use iron fastenings, rather than copper, for the SHSC reconstruction. The original Appendix 1 was cut.

8 References

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Appendix

Shipbuilding tools: fastenings and caulking

Most woodworking tools were used universally in different industries throughout the Anglo-Saxon period. Thus, tool finds usually cannot be associated with specific activities, e.g. shipbuilding implements cannot be distinguished from carpenter's tools. The most versatile objects were hammers, axes, and knives. Several notable examples of woodworking tools include the Mästermyr find from Gotland (Hillbert, 2018), and a few Anglo-Saxon hoards (e.g. Flixborough, Lincolnshire) (Leahy,2011). However, such finds are relatively rare. This section will briefly outline tools used in shipbuilding activities described in the report. Thus, only the tools used predominantly in the processes of fastening and caulking will be addressed.

The earliest evidence of specialised caulking tools (caulking iron and caulking mallet) is dated to the Medieval period (Cappers et al., 1997). However, their use is not required in clinker shipbuilding. One of the suggested methods for caulking (coating in tar and placing of fibrous material prior to fastening of the plank) would not require tools for its insertion, whereas wooden wedges (similar in function to caulking irons) can be used when seams are secured in place, or in repairs and maintenance of built vessels. Other implements include brushes and containers. Evidence from Birka includes vessels containing tar (Hennius, 2018: 1355), and associated textiles (Hagg, 1984: 11) were either a caulking material or cloth used for spreading of tar on the surface (instead of brushes). Pottery containers were widely used, although preservation bias should be considered when discussing the preferred material types.

The process of riveting required a few specific tools. First, holes were drilled in the planks with the use of augers. Two types are known from the period: handheld augers (potentially with a bowstring wrapped around it) and breast augers (Fig. 9).

Figure 9 *Breast auger in use (Vikingeskibsmuseet i Roskilde, 2019).*

Those are known from archaeological evidence (their iron components were found in e.g. Coppergate (Hall, 1982)), and iconography (Bayeux Tapestry (Fig. 10)). The latter type of augers is predominantly associated with shipbuilding (Hilbert, 2018: 12).

Figure 10 *A fragment of Bayeux Tapestry representing shipbuilding activities in the 11th century (La Fabrique de patrimoines en Normandie, 2017).*

Next, a rivet was hammered though the strake from the outboard side, and the rove was pushed down the shank. In modern reconstructions bucking irons are often used. There is no direct evidence of their use in the Early Medieval period, aside from the Mästermyr find (Arwidsson & Berg, 1999, 16). However, a bucking iron's construction (a socketed tool with flat head) is straightforward, and it might be an efficient option that does not compromise the overall process. Alternatively, hammers or even axes could be used.
Edberg suggested that rove blanks were made by blacksmiths and broken up by boatbuilder when needed (2009:7). Stirps of metal with punched holes would have facilitated easier transport between production centres. Such blanks were recovered from Hedeby (Crumlin-Pedersen,1997:121), and similar metal strips were found and Sitgtuna, Sweden (Edberg, 2009:7). It is also likely that some craftspeople mastered diverse skills, e.g. the Mästermyr chest contained tools for working with wood and metals (Hilbert, 2018).
Once the rove was pushed down, the excess length of the rivet would be cut off. Christensen suggested one method with the use of tools known from archaeological evidence: a nail shank must be bent, so the cutting force is parallel with the nail while a dolly provides support from the outboard. Then, a hammer and a chisel are used for cutting (1982: 336). However, incorrect execution may put significant strain on wooden strakes (ibid: 334).

A specialised tool for chopping off rivet heads was found in Sigtuna (Fig. 11), a site where rivets and rivet parts were found (Edberg, 2013). It was interpreted as a tool used in repairs or recycling of materials, which corresponds with traces of ship-repair and ship-breaking activities occurring on site. Such tool was also found at Paviken (Gotland), a Viking Age shipbuilding site (Christensen, 1982: 334) The feasibility of its use in removal of rivet tips could be considered.

Figure *11 A chisel-like tool for removal of rivets from strakes (Edberg, 2013: 202).*

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