Ring weave

A metallographical analysis of ring mail material at the Oldsaksamlingen in Oslo

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Abstract

This essay is a metallografic analysis of mail rings. It was written as part of the studies at the new conservation school in Oslo, Norway. Rings from three mail finds stored at Oldsaksamlingen in Oslo was studied. One of these was from the well known Viking grave from Gjermundbu, Buskerud. The rings were studied both longitudinally and in cross section. Especially the distribution of slag lines and distortions in the structures were noted. The conclusion was that the riveted rings was from premade wire and had been riveted using a tool with a negative impression of the rivetheads final shape, instead of directly with a hammer. Rings without any apparent joint was found to be punched from sheet metall. Some steps toward dating mail on the ring level is suggested.

Forsidebilde: Brynjemaker 1425 (Treue 1965)

Illustrations/pictures

All sketches and analyse pictures were made by the author. Where illustrations were taken from other sources that will be stated in the captions.

Tables

Measure data for each of the three analysed finds are depicted in the surveys of the single finds

C 27317	s.18
C 455	s.25
C 2616	s.29

Preface

My motivation to take on the ring weave-material sprung from my keen interest in processes connected to iron working. I work with traditional forging techniques myself and in addition to that I perform re-enactment fighting with weapons and armour from both the Iron Age and the Scandinavian Middle Ages.

Ring weave seemed to be a somewhat overlooked and deficiently researched find category to which few metallographical analyses had been performed. Based on the fact that mail garments have been an important part of armours for more than 1500 years I felt that it deserved a closer examination. Everything points towards that it takes a lot of effort to make ring weave and thus it is interesting to understand the production process, so that future research can place it in a fitting social context. During my work with this paper I have found out that a small number of surveys centred on ring weave have been undertaken in Denmark, Germany, England and the USA, though not all of them very convincing. In Norway the study of ring weaves is non-apparent despite the important Viking Age find from Gjermundbu consisting of an abundance of ring weave and a unique helmet. The samples analysed in this study stems from three finds kept at the Oldsaksamlingen in Oslo (C27317, C455, C2616).

The paper was written during the final semester at the School of Conservation in Oslo, spring 2000. The time remaining, accessible for this work, beside the lectures and practises in find conservation as a whole, has been strictly limited.

Acknowledgements

The author would like to thank: Kristin Sigurdardottir and Jerry McDonnel for the introduction to metallographical analysis during the studies in conservation. Heid Resi at the Oldsaksamlingen in Oslo who made me aware of important literature. Arne Jouttijärvi's work with Danish hauberks that gave me a better understanding of important features in the production of punched mail rings. Karin Knoph, Stock keeper at the Oldsaksamlingen who was very helpful and obliging at studies and photo sessions at the museum's storage. I also which to thank Henriette Lyngstrøm and Arne Emil Christensen for kind answers to questions asked in connection to this paper. And finally my fullest gratitude to my fiancé Lise who managed to endure with me - despite all late night analyses of mine.

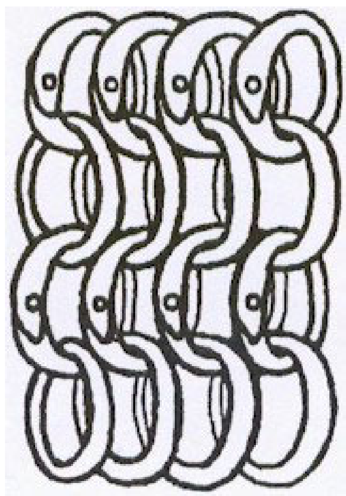
Vegard Vike

Innholdsfortegnelse Page

Introduction

The main aim with this paper is to present detailed surveys of three concrete Norwegian finds of mail garments, and to shed some light over the manufacture and technologies used to produce the rings and the weaves. Attempts will also be made to get closer to a valid method for the dating of ring weaves based on ring-level details.

Ring weave is the term for the material discussed in this paper. Ring weave is flexible and consists of metal rings, normally of iron. Each ring is connected to four others. One means to understand the material is to look upon it as chain links connected to each other side-ways. Ring weave has got two main directions of orientation, but in a majority of the known finds it is orientated in just one of them (as in the sketch below). All rings in a weave can be riveted but half of the rings can also be made solid, without visible joints.



Ring weave

In addition to the analysed material some other features from other ring weave finds will be mentioned and discussed. The paper is deals with finds from the Scandinavian Iron Age and Middle Ages. Scandinavian, English and some German material will be used as comparison at evaluations of the analyses.

The other ring weave artefacts at the Oldsaksamlingen have also been surveyed in connection to this paper, but pictures and information from those surveys will not, due to lack of time and space, be published here. Neither will some of the information from the analyses of the three mail garments discussed in this paper be included below due to the same reasons.

The final goal will be to make an English publication of the whole material at a later stage.

The use of tools in ring weave production will just be briefly looked upon; Some thought will be taken up to discussion, but a more thorough analysis will have to be made within some other work, preferably after that some experimental reproductions has been undertaken to test the probabilities of various hypothesises.

General state of the finds

A minor part of all ring weave finds consists of whole garments or pieces that can be reconstructed as such. The usual way to find it is as fragments or "clusters" of ring weave. Whether ring weave can be analysed or not depends fully on how well preserved it is. First and foremost this in terms is dependent on the state of preservation of the single rings, simply because these single elements connected to each other make up the whole garment. Some parts of a mail garment can be more corroded than other parts. Hence the shape of the garment can be totally lost while rings from various parts of it are so well preserved that they allow for a thorough analysis on the single ring level.

If the rings are heavily corroded and the original surfaces are distorted, a technical evaluation becomes more troublesome to achieve. To ad to that: a metallographical analysis will be hard to perform if no metal is preserved in the rings. If one manages to take metallographical samples from the rings that have been destroyed by corrosion it might be possible to evaluate the direction of the slag grain in the former metal. Much of the ring weave in the Swedish Vendel and Valsgärde finds from roughly AD 500 – 700 seems to be severely corroded and therefore hard to analyse, but that is absolutely not the case with all finds of ring weave. X-ray photographs are the best starting points for an evaluation of whether a metallographical analysis can be performed or not.

Another fact to consider is that corroded and decayed iron is very fragile, even after it has been brought to and treated by the museums. It can sometimes be virtually impossible to secure artefacts of iron from archaeological contexts from further decay, even after proper conservation and in dry storages. The severest "enemy" is Chlorides. Ring weave is especially exposed to it because of the thin gauge in the single rings, exposing a relatively large surface to corrosion. It might be rewarding to examine ring weave finds early and secure the information that can be gained from them, rather than to analyse them after a century or so of gradual decay and corrosion. Besides, a metallographical destructive analysis of ring weaves on ring-level does not take more than four rings per sampled garment or piece; two rings for each type. Considering that a mail hauberk consists of 20 – 40 000 rings it must be seen as a very modest operation.

The use of mail

Ring weave is a good material for armour. It posses certain fabric-like qualities and it is flexible, while the metal ads protections against cuts and to some extent against thrusts and arrowheads. The flexibility limits the protection against blunt trauma. Hence ring weave is at its best when it is combined with a thick padding between it and the body. Ring weave might also have been used as suspension and in small pieces as protective talismans against super natural forces.

The Iron Age: the use of mail garments during the pre-Roman and Roman Iron Age seems mostly to have been concentrated to shirts covering torso, arms and thighs to a greater or lesser extent (for example Malifilâtre 1993). Later during the Iron Age (Merovingian/Vendel Age, Viking Age) ring weave in addition to shirts, were used to cover throat and face, suspended from the lower rim of helmets (Vendel and Valsgärde – 6th – 8th centuries, Coppergate-8th century). From Valsgärde 8 it might be possible to interpret the ring weave-fragments fastened to two iron splinter greaves and one vambrace as mail-mittens and foot coverings. The find was earlier misinterpreted as a torso armour by Greta Arwidsson (1939, 1954).

The Medieval period: ring weave was used in armour covering the whole body during the early Middle Ages (hood, shirt, mittens and hosen). Especially during the 12th and 13th centuries ring weave was used for armour covering most of the body. Later, from the 14th century and onwards, metal plates gradually replaced it. Initially plate was only added for extra protection but later it replaced the ring weave. During the 15th and 16th centuries plate armour had taken over as general protection. Pieces of ring weave were used to cover spots that needed to be protected by extra flexible armour (the groin section and in the bend of arms and knees). Despite this, full mail hauberks/shirts, sleeves and hosen were still in use.

In the Arabic and Indian cultural spheres mail armour was in use up until the 18th and 19th centuries. In Norway ring weave was in terms used fore suspension of knife scabbards and for suspension of cowbells, at least in the recent past. Today it is used in butcher's gloves to protect the hands during the cutting of meat.

Bronze rings

Mail garments are usually made from iron, but for decorative reasons rings made from bronze and other copper alloys can be mounted in the ring weave, mostly along rims but also in simple patterns further into the garment (as on a garment from Visby 1361 –

Thordeman 1939). Bronze rings as decoration seems mostly to be a medieval feature, but on the Coppergate helmet (8^{th} century) a row of brass rings are mounted in the top of the mail aventail were it was fastened to the helmet (O'Conner 1992).

Analysis of the finds

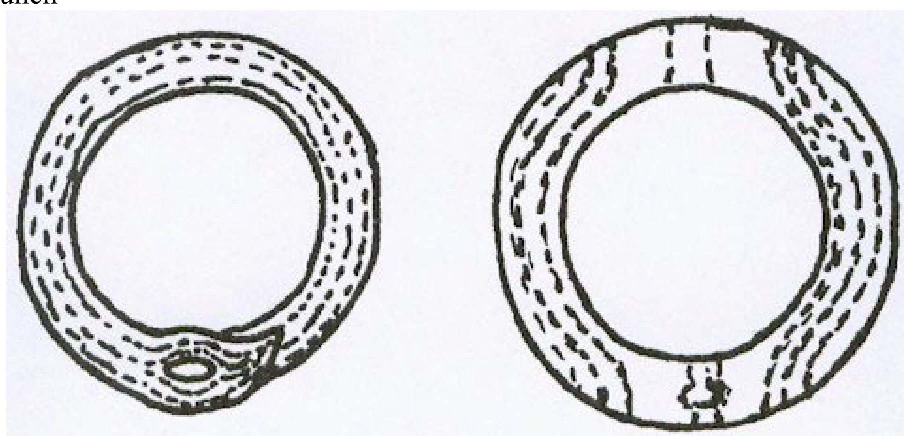
This paper deals with three finds of ring weave. These are all kept in the Oldsaksamlingen in Oslo. The Gjermundbu find is the only one of the three that, due to its context, can be securely dated to the Viking Age. The other two lack such clear contexts since they were found very early (already during the 18^{th} and 19^{th} century) without proper excavations.

The finds were analysed through samples of small, conjoined fragments of ring weave. Only parts of these samples were submitted to destructive analyses. Most of the rings from the sample-patches were measured and meticulously registered. Observations and interpretations were documented on a running basis. Riveted and solid rings were identified and the two types were accounted for separately. All data on each find was summed up and registered separately. The measurements were, among other utilities, meant as an aid to conclude whether the rings features regularities or irregularities in comparison to each other. This in terms can be used as a means to conclude how standardised the ring production was, and possibly if special tools were needed. The registration of data was also meant as an aid for further research and it will hopefully increase the accessibility to the finds; for, among others, non-Scandinavian researchers. My intention is therefore to re-work this thesis into an article or dissertation in English at a later stage.

The measurements were taken with a Vernier Caliper and registered with an accuracy of a tenth of a millimetre. Smaller details, such as rivet heads were measured under a Working Microscope (x40). The least corroded rings were chosen for the measurements, while the measures of heavily corroded, and thus distorted areas, were left out as misleading. Excluded samples are marked with a line (-). The length of the overlapping shanks on the riveted rings were sometimes hard to measure. Where this could not be done the measurements were replaced with a question mark (?).

The making of metallographical grinds was the more destructive part of the analyses. For to yield a good result metallographical surveys are dependent on that at least some uncorroded metal survives in the rings. Metallography means that the location of slag stripes, welding lines and various alloys, as well as traces of heat treatments in the structure of the metal is studied by means of microscopy. At least two rings per type (two riveted and two solid) are needed in a metallographic analysis. These were fixed in epoxy (Struers epoxyfix), one vertically and one horizontally. The samples were then roughly grinded with a rotating water grinder with 1200 grit.

After the grinding the samples were polished with diamond-paste with grain coarseness from 15 to 1. The samples were then studied to establish the distribution of slag lines before they were etched with 4 % Nital (nitric acid and alcohol). After the etching it was possible to evaluate alloys and grain sizes. The samples were used to study the rings both in plane and cross-section. The samples with rings in plane were cast with the rings laying flat. Plane grinds can clearly show whether a ring was made from drawn wire or punched from sheet metal, at least when the metal in the rings have a high content of slag stripes. Drawn wire will show slag stripes that follow the wires general curvature while the slag stripes in punched rings will be broken by the punch



Slag stripes are distributed differently in plan-samples made from riveted rings (drawn wire) than in plan samples made from punched rings (made from sheet metal)

Separate layers, partly in a deformed state, from the forged sheet metal can be identified in the sections of punched rings. Deformation caused by cold working will show since the crystalline grains in the structure are flattened if the metal has not been re-heated, allowing the structure to re-crystallize. The general orientation and location of the deformations can yield clues about the processes that took place in the making of a ring; punching of the rivet hole, the flattening of wire and so on. In samples made from riveted rings the rivet needs to be in the section along with the wire. A tangential grind sample of the rivet area was made on a ring from the Gjermundbu find as well as on one from the shirt from Verdalen. The shapes and deformations of the rivets could be studied more closely in these grinds.

There was not enough time to analyse trace elements in the slag inclusions. Some researchers use such trace elements to evaluate the origin of the metal (Arne Jouttijärvi 1996). Analyses of trace elements calls for thorough examination with a Scanning Electron Microscope and that proved too demanding to fit within the limited time frame set-aside for this paper.

To allow for studies of the joints of the ring weaves in a scanning electron microscope, single rings were opened by the rivets. All details were photographed and documented.

C 27317 i - Gjermundbu, Buskerud

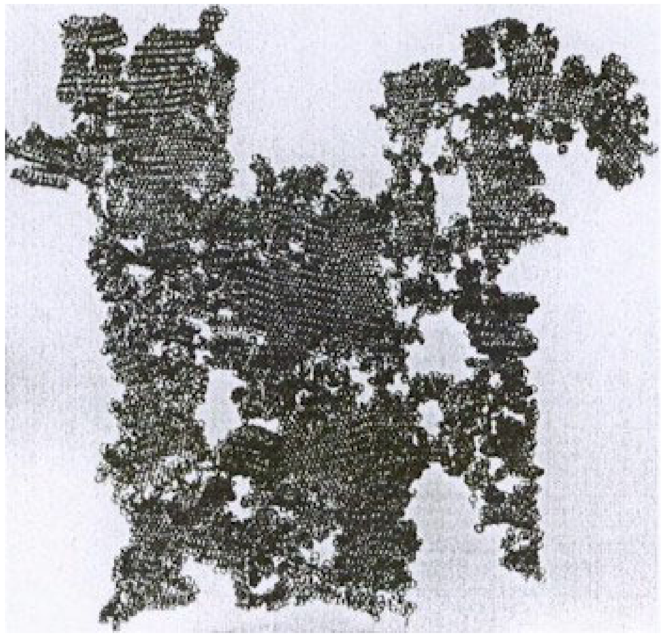
The Gjermundbu find is a grave find dated to the Viking Age and the 10th century (Grieg 1947). It was found and excavated in 1943, partly illegally, before the arrival of archaeologists at the find site. The find is made up by two different graves (I & II). Approx. 85 fragments of ring weave were found in grave I along with a large number of other artefacts, among others a double edged sword with a chape of bronze along with a round helmet with a spectacle-shaped visor. The grave is a cremation burial.

Two metal rings are attached to one of the helmet's plates. It is therefore possible that not all of the ring weave fragments belonged to a shirt; some of them could have been parts of a protection for the neck-area that was suspended from the brim of the helmet (Munksgaard 1984). Several spectacled helmets from the Swedish Vendel period had such suspended ring weave protections (Arwidsson 1942, 1954, 1977). "*Right under the surface of the charred layer, which was not very deep, lay the hauberk like it had been folded neatly. Parts of it had slipped down somewhat and lay on it own by the side of the rest.*" (Grieg 1947; Introduction). The piece of ring weave laying by it self could possibly be the neck protection, the aventail.

Preservation and current state

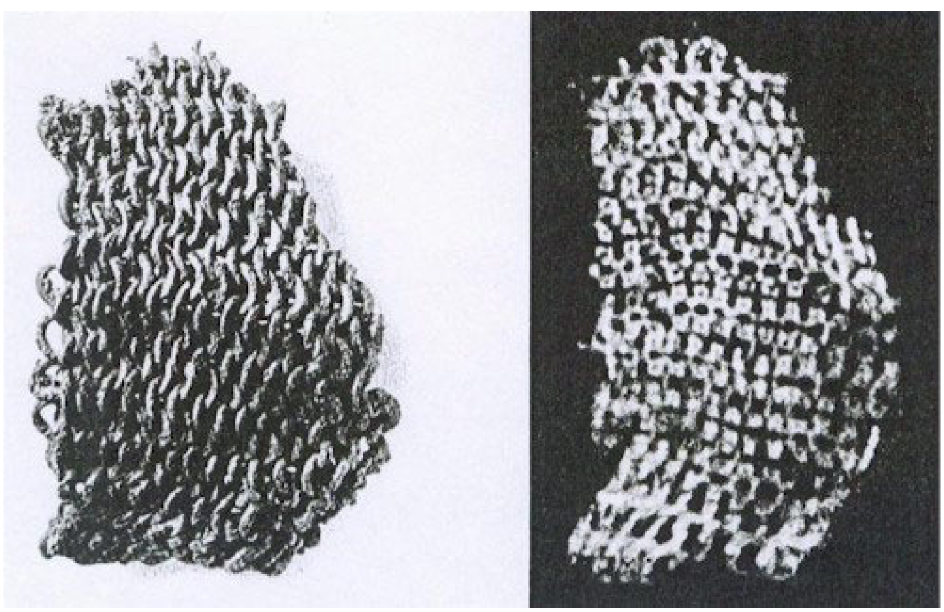
Apparently the ring weave lay folded prior to corrosion. The originally flexible material has been totally stiffened by corrosion products and fixed in the folded shape. Several fragments had fractures where the cross-sections of the rings are clearly visible. The pattern in the ring weave is clearly visible at some parts of the fragments, but it is partly covered by corrosion. Some of the fragments include rings that seem to be of a heavier gauge than the rest, this is probably due to corrosion below the surface. The fragments are treated with wax, but the surface corrosion has not been removed.

Some of the larger and flatter ring weave fragments are on display in the Viking Age exhibition in the Oldsaksamlingen in Oslo. They are mounted to a Plexiglass plate. They were mounted to it for to be a part of the large Viking Age exhibition in Paris in 1992. These fragments were conserved prior to the mounting on the plate; this included sandblasting (Torrun Klokkernes, Conservator, Oldsaksamlingen, Oslo; verbally, May 2000). The author has not been able to find any x-ray photos from this conservation.



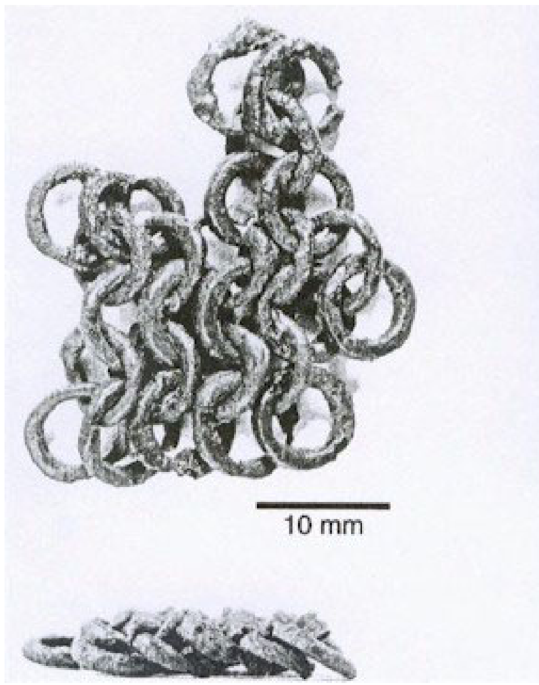
The displayed fragments from Gjermundbu (picture from the conservation report)

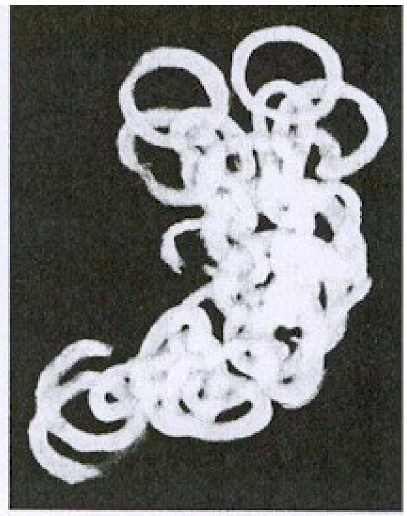
One fragment is currently on display in a travelling exhibition in USA in combination with the millennia celebrations. The theme for that exhibition is the Viking Age and all Scandinavian countries contribute with artefacts. Before leaving for USA this fragment underwent conservation by Torunn Klokkernes and an x-ray photograph was taken. The picture shows that it is heavily corroded with many hollow rings that are only held together by fragile shells of corrosion. The possibilities for further conservation and examination of ring weave in this state are indeed very small.



Fragment on display in USA (Pictures from conservation report – 2000)

Not all of the fragments from Gjermundbu were so degraded by corrosion. The sample piece made available for the analyses in this paper proved to be in a very good condition. On most rings only the surface has been corroded, leaving large amounts of metal preserved underneath it. Four rings are so corroded that they have fallen apart, leaving them with open gaps, but none of the rings are fixed to each other by corrosion. The sample piece was still somewhat folded and stiff from wax treatment when the x-ray photograph was taken, but un-corroded metal is clearly visible in the cores of the single rings.





The fragment made available for analysis.

On most of the rings a representation of the original surface can be seen in the corrosion layer, many also suffered some flaking in this layer and others still have swollen to a more thick and uneven appearance due to sub-surface corrosion pushing the surface outwards. The corrosion surface consists of a smooth, hard and black layer, probably magnetite. At single spots there are red patches on the original surface. They probably consists of hematite, a ferric corrosion product that appears at heating above 200ºC. Hematite was to be expected on the metal; since the find comes from a cremation burial the ring weave has been submitted to heat in the funeral pyre.

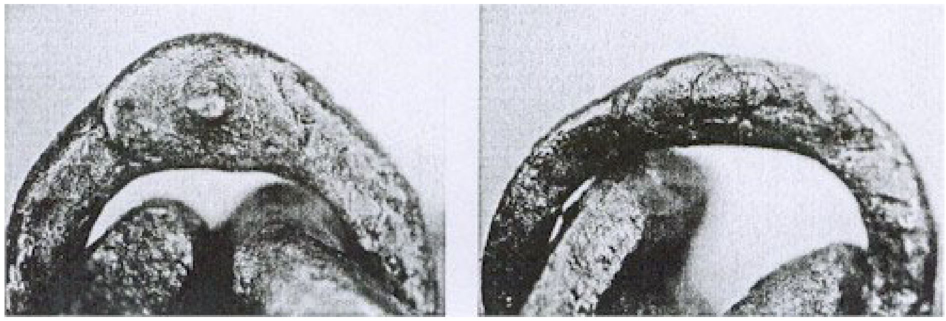
The fragments mounted for display at the Oldsaksamling in Oslo seem to be in good condition. The other fragments in the storages vary somewhat in their state of decay, but there is quite a lot of corrosion, mixed with conservation-wax on the surfaces of the rings. X-radiography could tell much about the fragment's current state.

The severely corroded fragments that were conserved for the exhibition in USA all showed signs of active corrosion, and hence it would be of great interest to evaluate the state of conservation for the remaining fragments as well. During the analysis of the find copper residue was found on the iron, *below* the corrosion layer on some of the rings. The copper could have increased the corrosion of the iron since the two metals would form an electrochemical cell together in which the less noble iron would act as an anode for the nobler copper. The state of the metal suggests an anaerobic and possibly somewhat alkaline soil condition; artefacts of bone were also recovered from the grave.

Surveys

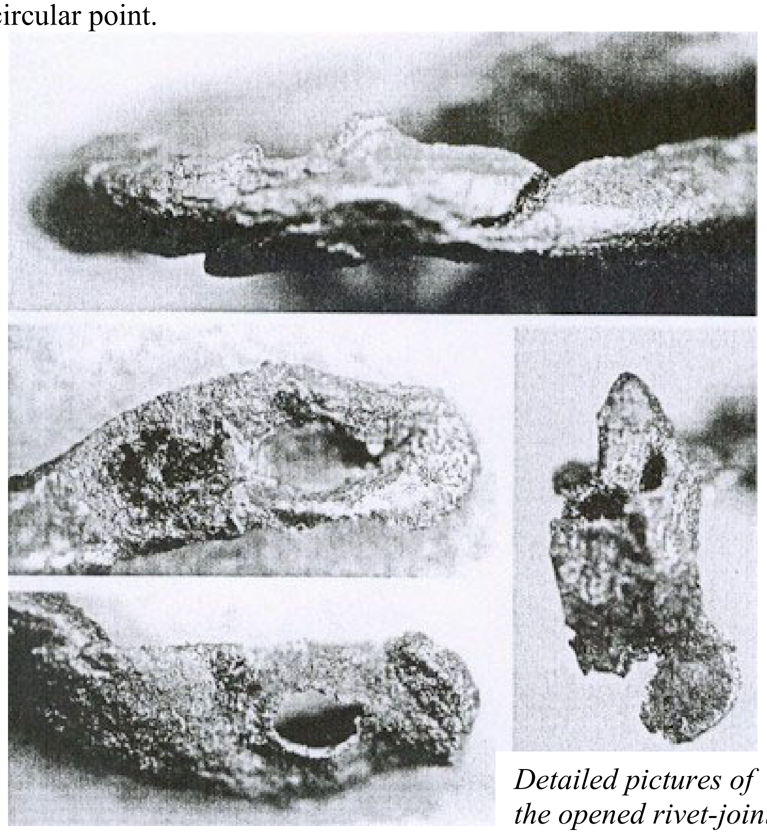
The sample piece made available for analysis consisted of 26 rings. 6 were used in destructive analysis and the rest were later returned to the collection. 16 rings were solid, without trace of joints while 10 were riveted.

The riveted rings are made from wire with a round cross-section. Rivet heads are only visible on one face of the rings, and all rivet heads are on the same face of the piece. On most surviving garments that is the outside. The rivet heads are round and hemispherical. The size varies somewhat. On the rings where the surface is best preserved it can be observed that the rivet heads has an evenly curved outline without facettes. The even surface implies that a setting tool has been used to shape the heads of the rivets. The rivets are not visible on the "rear" sides of the rings. The overlaps by the riveted joints always run in the same direction – counter clock-wise. The riveted areas on the rings from Gjermundbu are somewhat more varied than on the hauberk from Verdalen (C455), and the riveted area is somewhat less compressed in comparison to the wire. The less significant compression is probably due to the rivets being much thinner. Large differences in the riveting could be interpreted as traces of less standardisized production, possibly simpler tools. The wire-ends in the overlaps are pointed.



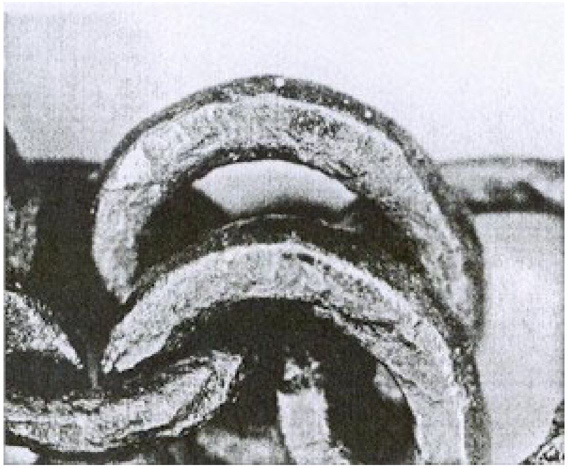
Examples of riveted rings

One ring was opened by the riveted joint, where after both the joint and the rivet was studied. The rivet is fairly round in section, though more oval and wide towards the back end. The rivet hole is not evenly round, more like a pointed oval formed from a widened split. This might be an indication that the tool used to punch the hole had two edges and was formed like a chisel rather than a circular point.



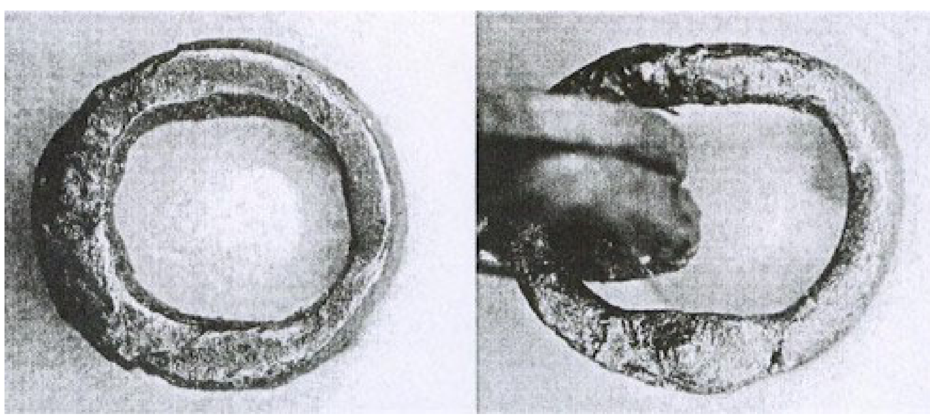
Detailed pictures of the opened rivet-joint

The riveted and the solid rings are consequently placed in every other row. The solid rings are of a heavier gauge than the riveted and they have a square section that is somewhat rounded-off on some.



The solid rings have an outspoken square section

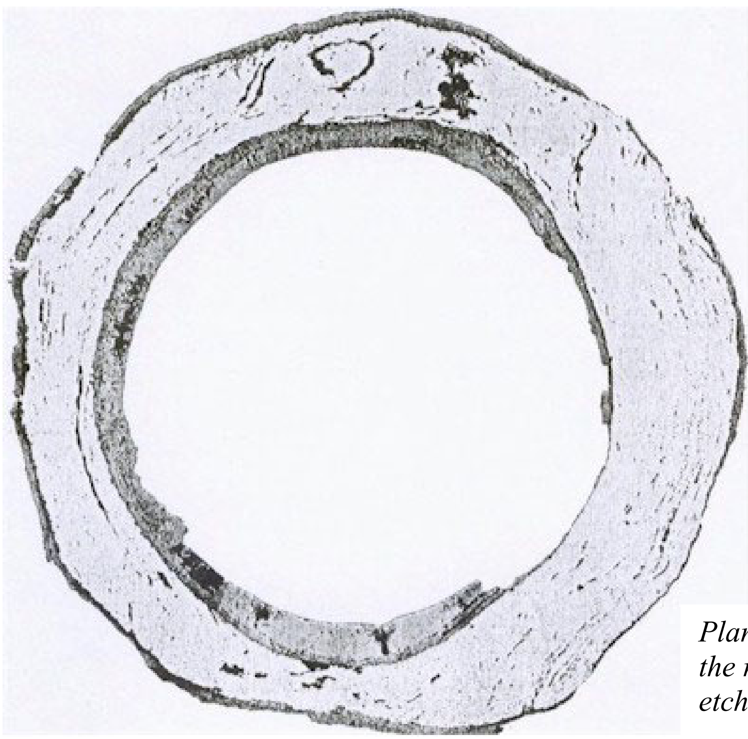
The solid rings tend to look somewhat irregular. At a closer examination of the best-preserved rings it could be established that the outer circumferences were quite round, while the inner circumferences tend to show four irregularities, best described as four corners. This feature could indicate outright wear. Each ring is linked to four others that fit well into the irregularities. A closer examination of the riveted rings show that they feature the same corner-like tendencies. The metal is not worn off, but the metal wire has given in and bent.



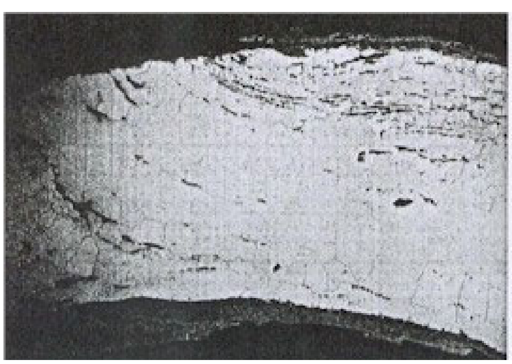
The rings tend to feature four corners

Metallography

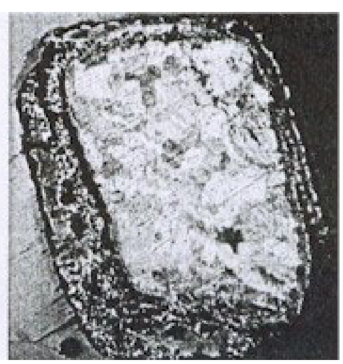
The fact that the mail garment has been burnt is clearly visible in the metallographical survey. The heat has brought the metal to re-crystallize. Due to that all traces of cold working have disappeared from the metal. The included slag stripes are undisturbed by the heat, and important information is still available. Both the solid and the riveted ring show coarse and homogenous ferrite in the plane grinds. The wire in the riveted ring is almost free of slag inclusions, but the few that do exist follows the curvature of the wire in a very precise manner, indicating that the wire was drawn. The solid rings have quite a few slag stripes; these breaks out of the rings general outline at several points, a clear indication of punching. A square cross-section is also a sign that punching was the method of production.



Plane grind of the ring. Before etching.

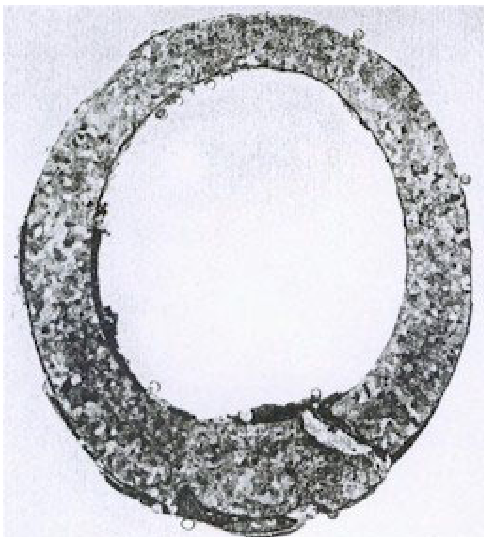


Slag stripes breaking out of the wire – 50x

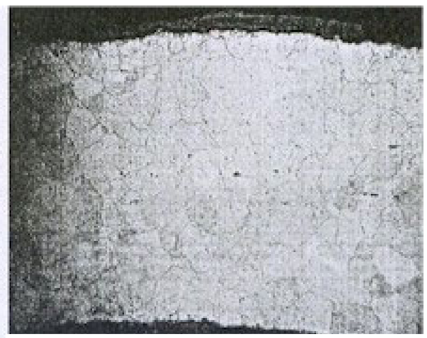


Section of the wire

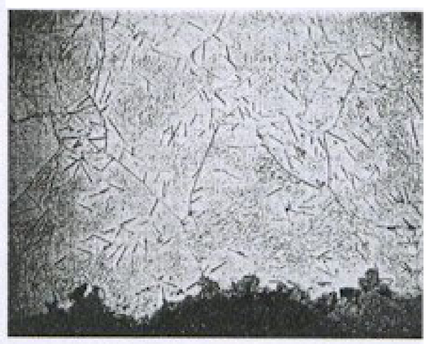
Parts of the riveted ring consisted of an intriguing and not so common alloy. In the part furthest from the rivet the concentration of a needle-like structure, behind the outer ferrite grains, gradually increased. These proved to be needles of nitride, indicating the presence of a nitrogenous alloy. (Samuels 1999:416-424). Nitrogen is taken up interstitially by iron much like carbon, at a larger rate though and at a lower temperature. Carbon and Nitrogen can bind to each other in stabile phases and thus create even harder structures. Strangely enough the nitride needles were not found at the riveted sides of the rings. One riveted ring, grinded down in section, showed the same partition of nitride needles - plenty by the “rear” end but not one single needle by the riveted part. The nitride needles are not concentrated to the surface of the metal, they are found in the core as well. The solid rings also occasionally show nitride needles, but in smaller quantities than in the riveted ones.



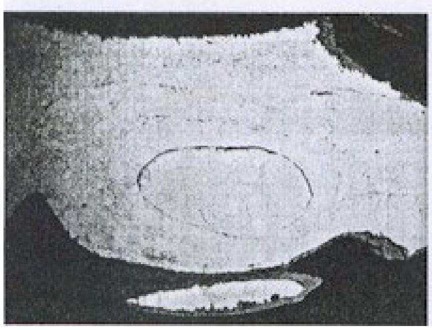
The outline of a complete riveted ring



A piece of wire with nitride inclusions – 50X

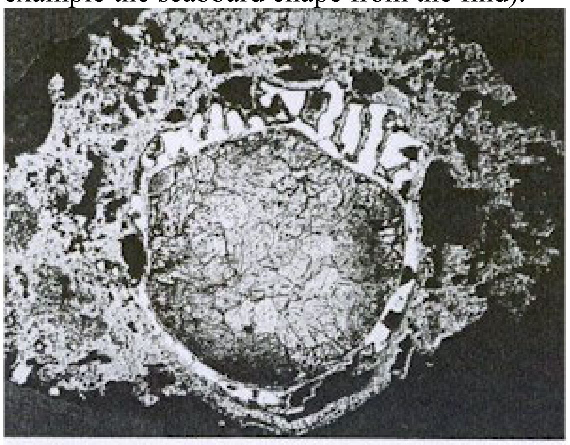


Nitride needles – 500X



By the rivets, no visible nitride needles – 50X

Another interesting feature, particularly visible from the cross-sectional cut of a riveted ring, is a coating of Copper on the wire surface. It was observed to a lesser extent on other rings as well (both on riveted and on solid ones), but not on all examined rings. Metallic copper was present in an uneven layer close to preserved iron on the rings, below the original surface. The copper was analysed by means of SEM and found to be pure, without alloy-metals. A probable explanation for the presence of the copper is an electrolytic reaction in the soil after the deposition – a result of copper being a nobler metal than iron. A bronze artefact has probably been corroding near the mail garment (for example the scabbard chape from the find).



Sectional cut of the wire in a riveted ring. Deposited copper and nitrides. 50X

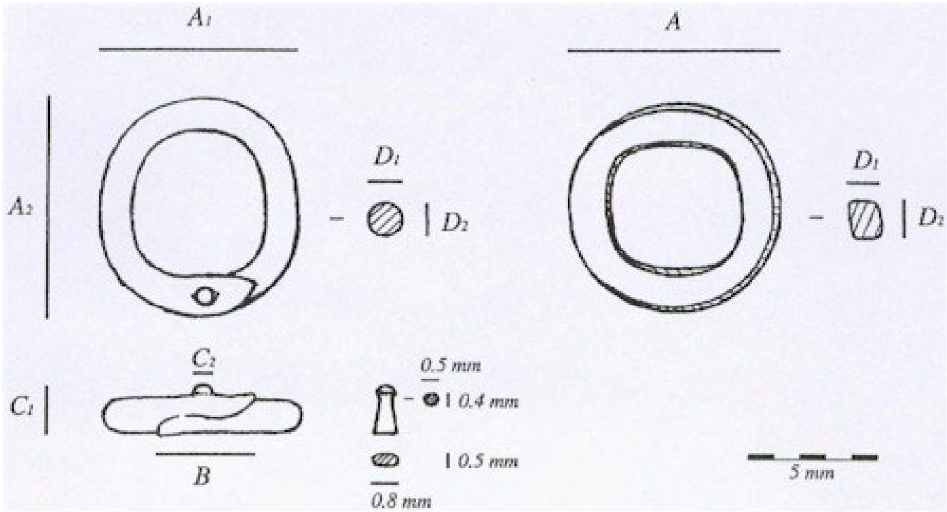
Detail of the deposited copper, un-etched. 200X

In the corrosion process, ions of copper will be dissolved. When iron is present nearby the copper ions will precipitate as metallic copper on contact, the iron will then act as a sacrificial anode (and corrode even more). The precipitation only takes place when the ions get in galvanic contact with the iron. This explains both that the copper is pure and that it is deposited below the rings original surfaces.

Weight (gram)

The samples total weight:	- 6.09 g			
Single sampled solid rings:	- 0.29	0.26	0.28	= 0.28g
Single sampled riveted rings:	- 0.15	0.18	0.17	= 0.17g

The approx. 85 ring weave fragments have never been weighed and they are now mounted for display. Since the total weight is of interest an approximation will be made. The stored fragments weighed approx. 2900 gram. A tally of the displayed fragments gave an approximate number of 11-12 000 rings. Drawing from the average weight of the single rings it weighs 2.6 kg. All the fragments put together weighs roughly 5.5 kg and they consist of 24 – 25 000 rings. Without a thorough study of all the fragments it is hard to tell how representative that is for to how much ring weave there was in the grave to start with and how much that have been destroyed by corrosion. The current weight indicates that much more ring weave than needed for a ring weave neck protection is present in the find, but it would still not have made up a sufficiently large shirt.



Measurements (millimeters)

Riveted ring nr.		1	2	3	4	5	6	7
Ring	A'	7.5	7.5	7.6	7.7	7.7	7.8	8.7
	A^2	8.0	8.2	8.2	8.1	8.1	7.4	7.9
Overlapping	B	3.9	?	?	4.0	-	4.2	3.9
Rivet - length	C'	1.8	1.8		1.9	-	1.6	1.8
- head	C^2	0.7	1.2		0.6	-	0.8	0.5
- diameter	only one opened ring 0.5 x 0.4 - diameter towards the rivet heads 0.8 x 0.5 - diameter towards the rear							
Width of wire by rivet		1.8	1.9	1.9	2.4	-	1.6	1.8
Wire	D	1.3	1.3	1.3	1.3	1.2	(1.0)	1.2
		1.4	-	1.3	1.3	1.2	(1.1)	1.2
		1.3	-	1.3	1.3	1.2	(1.2)	1.2

Solid ring nr.		1	2	3	4	5	6	7
Ring	A outer	8.0	8.1	8.3	7.8	8.4	7.5	8.4
		8.0	8.1	8.2	8.0	8.0	8.4	7.8
	A inner	4.8	4.9	4.9	5.0	5.0	4.7	5.1
		4.9	4.9	4.8	4.9	5.2	5.0	4.8
Wire	D^1/D^2	1.3/1.3	1.4/1.5	1.6/1.6	1.9/1.4	1.3/1.7	1.7/1.6	1.6/1.6
		1.3/1.3	1.6/1.6	-	1.7/1.4	1.7/1.7	1.6/1.5	1.6/1.6
		1.8/1.7	1.2/1.5	-	1.1/1.4	-	1.6/1.5	1.4/1.5

(D^2 = ring gauge)
- = misleading due to severe corrosion
? = could not be measured

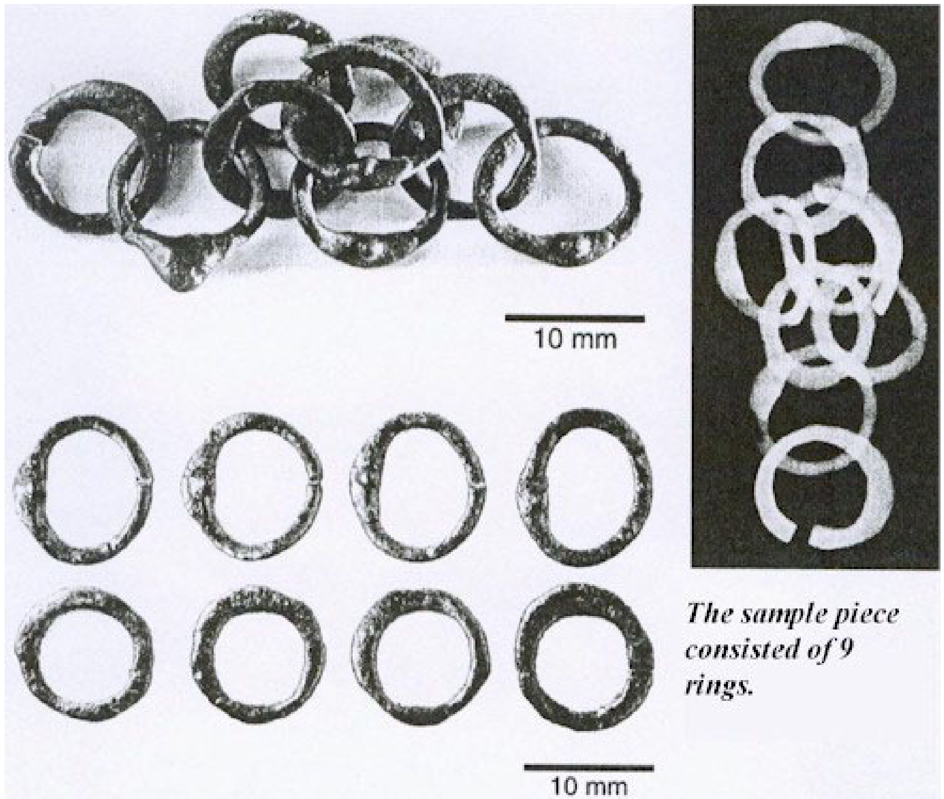
C 455 – Verdal, Nord-Trøndelag

This is a mail shirt of uncertain provenience. For a long time it was kept in Verdalen (Norwegian county), it was deposited at the museum in 1833. The shirt is relatively well preserved, but it has some holes and it is torn by the edges. The sleeves are of mid length and reaches roughly to the middle of the lower arms. The neck opening is fairly round. The metal in the rings is well preserved, but it has a layer of corrosion on the surface.

Measurements:
85 cm long
63 cm wide below the sleeves
Approx. 1 metre wide over the shoulders including outstretched sleeves.

After a closer examination of the shirt I would, judging from the outline of the whole garment and the shape of the individual rings, suggest it to date from the 15^{th} or the 16^{th} centuries. Several preserved German shirts from that period are comparable to C 455 (Pfaffenbichler 1992).

The shapes of the single rings also fit such a dating (Smith 1959, Fredman 1992:23-55).

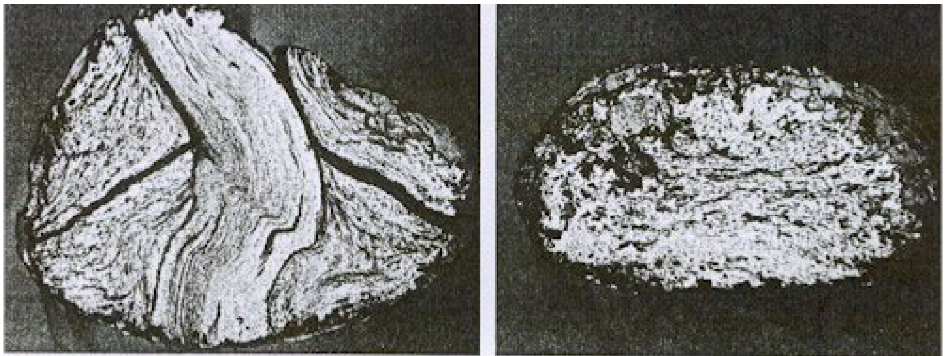


The sample piece consisted of 9 rings.

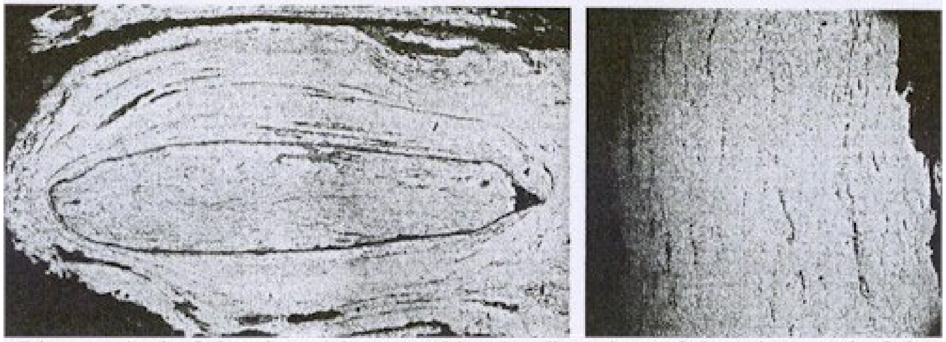
The sample piece consisted of 9 rings, 5 riveted and 4 solid. The ring weave was covered by some conservation-wax. It was necessary to cut the riveted rings through the side opposite to the rivet to free undamaged solid rings for the metallographical analysis.

Riveted rings

Solid and riveted rings are mounted in every other row. Rivet heads are found on one side of the riveted rings, and these are always on the outer face of the garment. All the riveted rings are overlapped in the same direction – clock-wise. The ends of the ring wire are pointy by the overlap and the points tend to turn inwards towards the centre of the rings. By the riveted area the wire is oval in section. By means of the metallographical examination it could be established that the layers are compressed towards the middle of the section, and in the plane grind it could be seen that the grain size was smaller towards the centre of the wire. This is probably a caused by a wire with a round cross-section being compressed to a more oval shape. To ad to that there are slag stripes in the metal that run in general curvature of the wire. The stripes are pressed out to the sides by the rivet, but they are not broken. The rivets broad, flat shape is clearly visible in the plane grind. Apparently the tool that made the rivet hole had the outline of a flat, double-edged point. The exit hole by the rivet head is shaped like an elongated, extended cut in the direction of the wire. The metal in the riveted rings is homogeneously ferric.

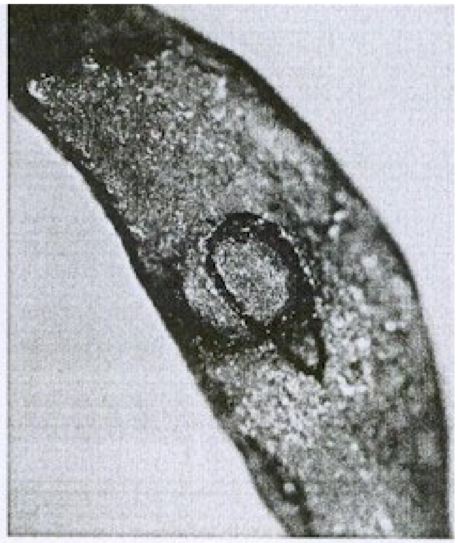


Sectional cuts in a riveted ring by the rivet and in the wire proper. The deforemation is clearly visible.



Plane grind of the rivet (elongated in the direction of the wire) and of the full width of the wire.

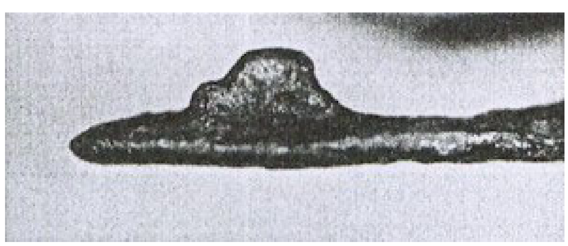
There are clear signs of a systematic approach in the riveting. The rivets have the same length on all examined rings, down to a tenth of a millimetre. The rivet heads have an even hemispherical shape that is fairly alike between the individual rivets. An interesting detail is that the rivet heads seems to consist of metal from the ring-wire to a large extent, along with the metal from the rivets.



A mail maker using a pair of tongs to mount rings in a hauberk (Treue 1965)
A riveted ring from C455 that shows clear signs of a special tool by the rivet.

This implies that the riveting was made by means of a tool with the negative shape of a rivet heads carved into one face. It is tempting to interpret this riveting tool as a pair of tongs. Contemporary depictions from the 15th and the 16th centuries show mail makers using a special pair of pliers in the mounting of ring weave. A two-piece swage, used together with a hammer might also have served the same purpose.

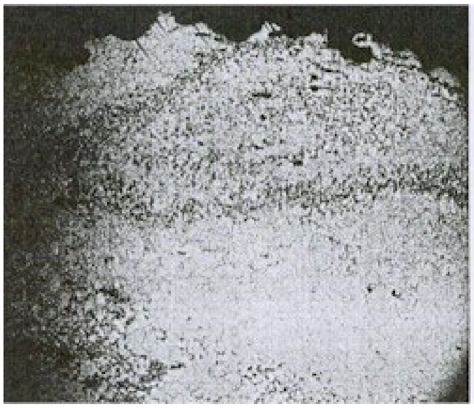
Two rings were cut open by the rivet for to allow a closer examination of that area in cross-section. One of these rings was later used to make a tangential grind of the riveted area.



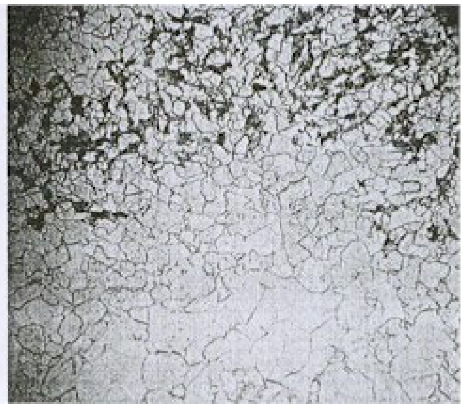
A rivet from an opened ring seen from the side. The special tool used to compress the rivet head has deformed the edges of the rivet.

Solid rings

The metal in the solid rings showed to be a lot more heterogeneous than in the riveted ones. In the plane grind ferric and perlitic iron can be seen deposited in uneven stripes following the curvature of the ring. An explanation for this phenomenon is given in the general discussion on technology in this paper. The perlithic areas seem to hold enough carbon to be on the verge of being hardenable, but the metal show no sign of such actions.

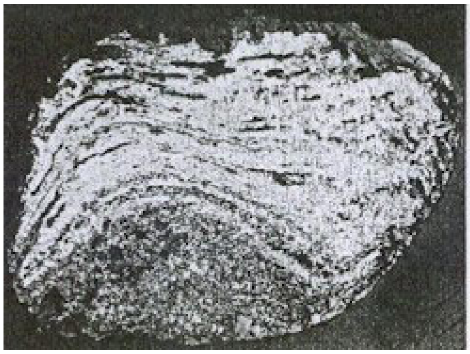


Heterogeneous layers can be observed in the plane grind – 50X

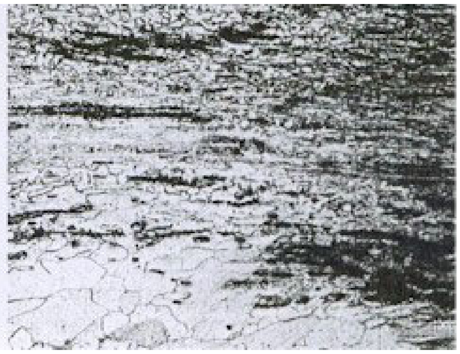


Perlite and ferrite in a lovely mixture – 400X

The slag stripes in the rings are quite obscure, but after an extra plane grind had been performed it could be established that they were partly running quite contrary to the wires curvature, an indication of punched rings. In the cross-sectional cut several indications of punching could be observed. Layers of perlite, ferrite and impurities were visibly deformed towards the edges of the cut. In addition to that, the grains were compressed in plane with the ring. Hence it could be established that the metal had not been heated after the cold treatment – the rings were punched from sheet in a cold state. The rounded-off edges that can be seen in the sectional cut do not seem to have caused any further disturbance of the layers. It is therefore justified to assume that the rounded-off edges were made so by grinding and not by working in a swage.



Cross-sectional cut with heterogeneous layers in plane with the ring – 50X



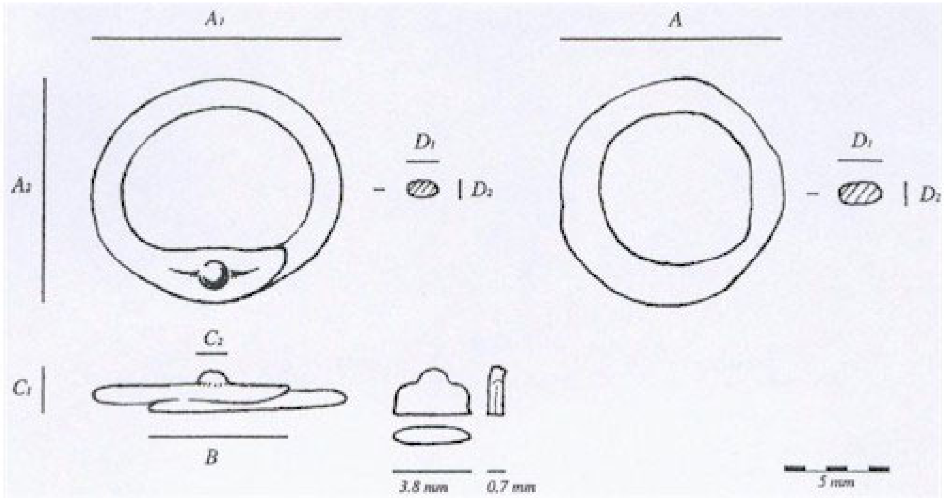
Details of the sectional cut – 200X

The solid rings have, despite an uneven wire-width, a very even gauge. This fits well with the interpretation that they were punched from metal-sheet. The width of the wire is extremely uneven though, possibly a result of grinding after the punching. Another explanation could be that the rings have been worn down by use, analogues to the ring weave from Gjermundbu (see the corners in C 27317).

Weight (gram)

The total weight of the sample piece	- 2.69 g				
Single solid rings	- 0.31	0.25	0.41		= 0.32 g
Single riveted rings	- 0.28	0.28	0.28	0.29	= 0.28 g

The whole shirt weighs approx. 8 kg. This gives, from the average weight of the single rings, a total amount of approx. 27 000 rings in the shirt



Measurements (in millimetres)

Riveted ring nr		**1**	**2**	**3**	**4**	**5**
Ring	A^1	12.5	12.6	-	12.2	12.3
	A^2	11.5	11.0		11.1	11.0
Overlap	B	5.8	6.4	7.0	6.2	6.4
Rivet - Length	C^1	2.0	2.0	2.0	2.0	2.0
- Head	C^2	1.4	1.5	1.4	1.6	1.5
Wire	D1/D2	1.5/0.8	1.6/0.7	1.6/0.7	1.4/0.8	1.5/0.8
		1.5/0.9	1.6/0.7	1.6/0.8	1.5/0.8	1.5/0.8

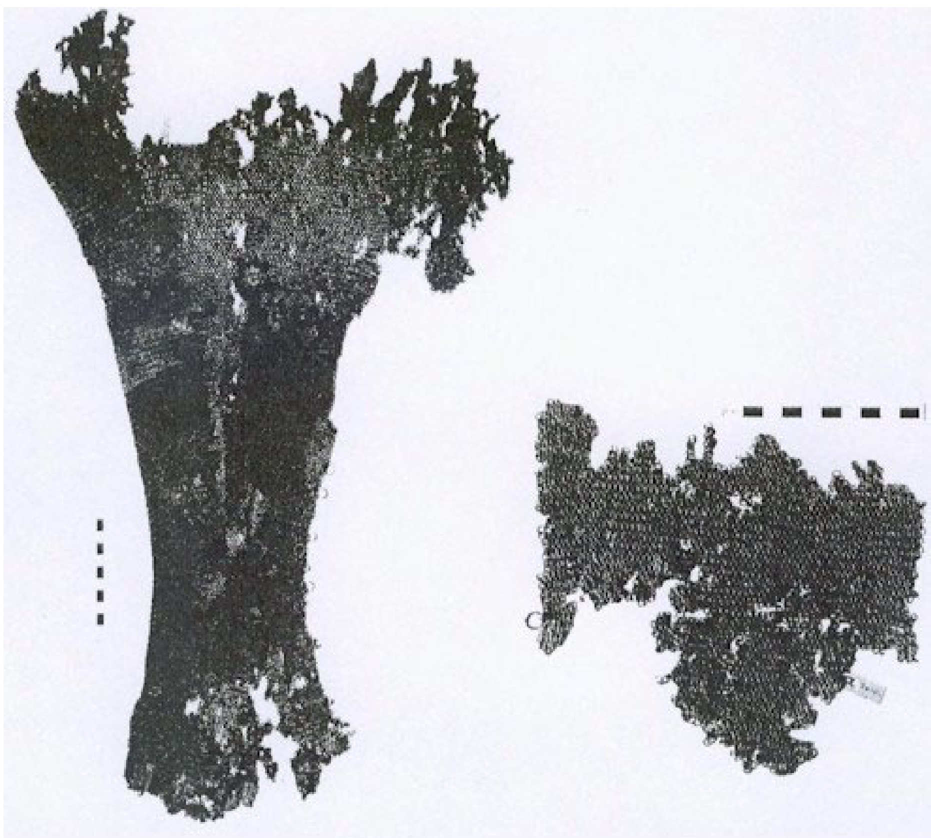
Solid ring nr.	**1**	**2**	**3**	**4**
Ring				
- largest A-outer/A-inner	12.0/7.5	11.2/7.3	11.3/7.4	11.0/7.4
- smallest A-outer/A-inner	11.0/7.3	10.3/7.4	10.6/7.6	10.5/7.3
Wire				
- largest D^1/D^2	2.7/1.1	2.0/1.0	2.1/1.1	2.3/1.1
- smallest D^1/D^2	1.5/1.2	1.4/0.9	1.0/1.0	1.1/1.0

(D^2 = ring gauge)

- = misleading due to severe corrosion
- ? = Could not be measured

C 2616 – Møllerdalen, Buskerud

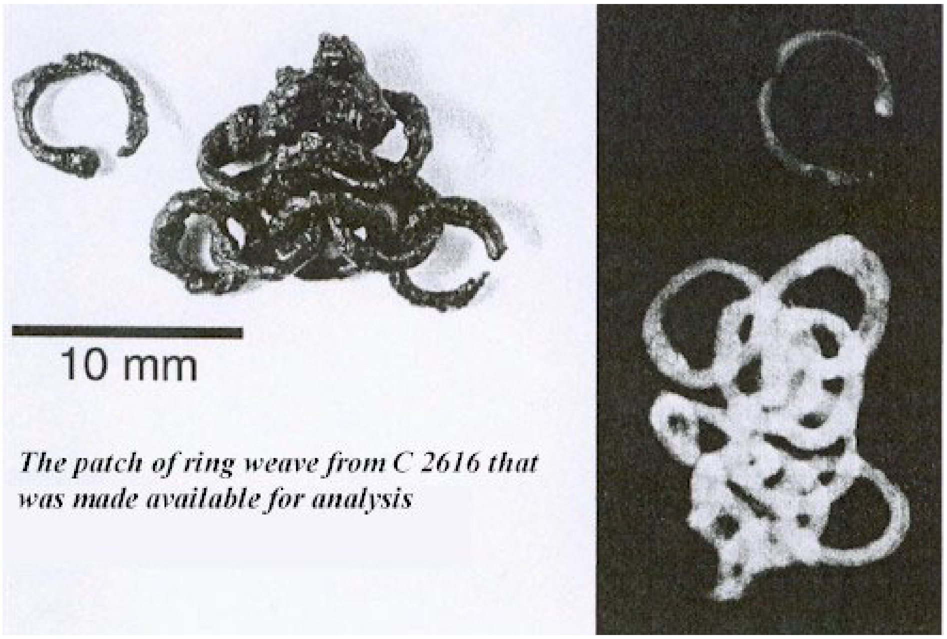
This is a fragmentary find of ring weave that was deposited at the Oldsaksamlingen in the 19th century. The rings are unusually small. The fragment was found together with a ring weave hosen (C 3250), a ditto gorget (C 3108) and pieces of a sleeve (C 2314). Both 3250, 2314 and 2616 have rings of a similar size, but pieces of 3250 and 2314 are additionally made up of rings of an even smaller size. The hosen (C 3250) show a split in the leg part, along the edges of the split there are several sets of lacing rings. These are of double size compared to the largest rings in the weave and they are riveted. The surveyed fragment (C 2616) had such lacing rings fastened by the edge and it is therefore most probable that it is a part of the other hosen in a pair with C 3250. The better-preserved hosen is designed for a left leg, at least if one interprets the lacing as running on the back of the leg. If that is a correct assumption, fragment C 2616 will have been part of the right hosen.



C 3250 - The complate hosen

C 2616 - the surveyed fragment. Note the larger lacing ring

The state of preservation varies, but generally it is good, especially considering the thin wire-gauge. It seems like all four pieces of ring weave from Mølledalen belongs together. If that is a correct assumption the find can be dated to the 15th century by typological features in the gorget.

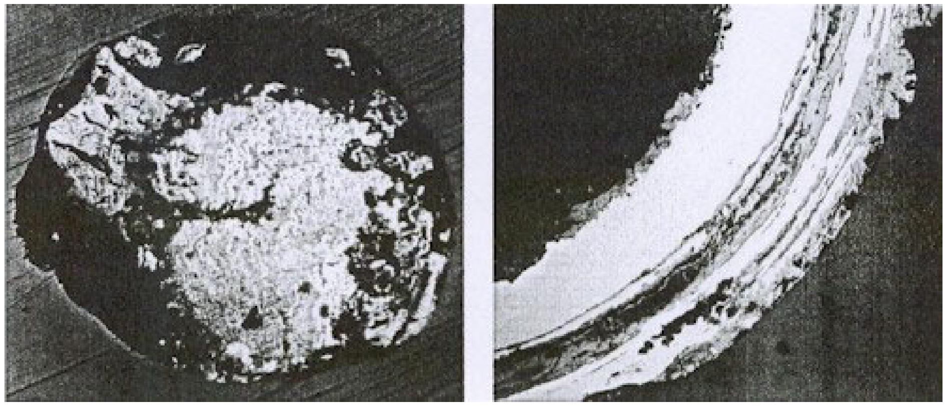


The patch of ring weave from C 2616 that was made available for analysis

The sample patch consisted of rings with some surface corrosion and it does not stem from the best-preserved part of the fragment. The rings were covered in a reddish conservation-wax. All rings were riveted and the overlaps ran anti clock-wise. The rivet heads were quite hard to separate from the rest of the rings in some cases, but generally they seemed to be facing the same side of the patch. On the hosen C 3250 the rivet heads are facing inwards, a fairly uncommon feature. The rivet heads were not very prominent, so whether they face in- or outwards are probably of less significance. The hosen might have been turned in side out at some point since two of the lacing rings are now positioned on the inside at some distance from the current edge.

The riveted areas were thoroughly studied on two opened rings and the rivets were measured. The wire ends are bluntly cut in the overlap and not pointy, the latter is otherwise the most usual feature on riveted rings. The wire is round in cross-section. The metallographical examination in plane shows that the slag stripes are concentrated to the core and that they follow the overall curvature of the wire. This implies that the wire was drawn. An explanation for the slag concentration in the core is given in the sectional cut:

A clearly visible U-shaped concentration of impurities was to be seen in the centre of the cut. The wire was probably drawn from long, flat iron blanks, cut out of sheet metal. These have, either intentionally or spontaneously, formed hollow “tubes” when drawn



A combination of the cross-sectional cut and the plane grind of the ring was used to establish that the wire had been made from flat iron strips, folded length-wise while drawn.

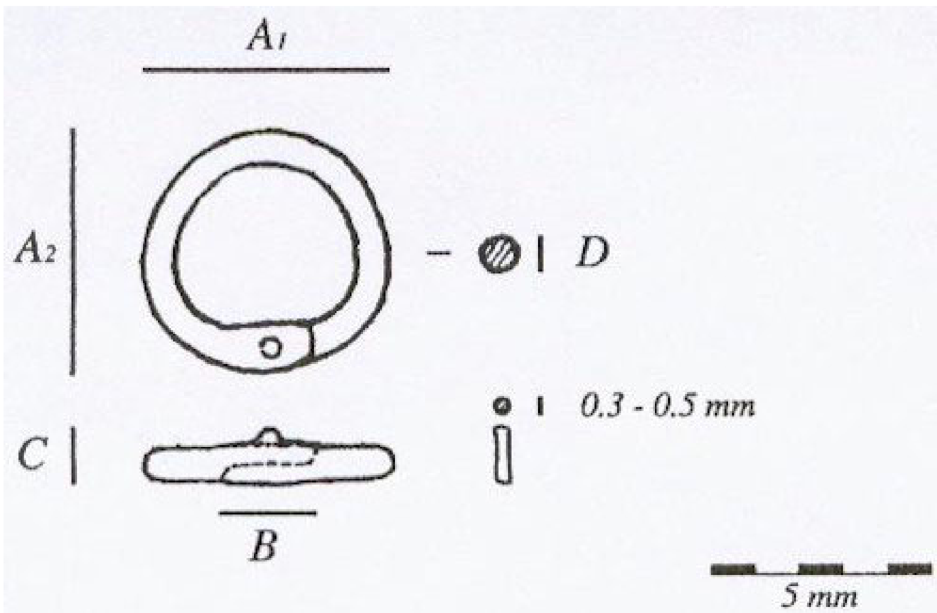
Further, The metallographical survey showed ferric iron, a round-sectioned rivet and deformations by the edges of the rivet hole. The rivet hole seems to have been larger than the rivet.

Detail from the riveted area – the rivet hole is larger than the rivet - 100X

Weight (in gram)

The total weight of the sample - 0.68 g
All rings were riveted - totally 10 ½ rings gives an average weight of 0.065 gram per ring

The preserved hosen, C 3250, which probably made up a pair with the fragmented C 2616, weighs 1533 grams. Thus the hosen is made up of approximately 24 000 rings.



Measurements (in millimetres)

Riveted ring nr.		**1**	**2**	**3**	**4**	**5**	**6**	**7**
Ring	A1	-	5.0	5.5	5.6	5.5	5.4	5.5
	A2	-	5.5	5.4	5.4	5.5	5.3	5.3
Overlap	B	2.4	?	?	2.4	?	2.3	2.3
Rivet -length	C	1.3	1.5	1.2	1.3	1.2	1.3	1.3
-diameter		-	-	-	-	-	0.50	0.30
Wire	D	0.85	0.9	1.0	1.0	1.0	1.0	1.0
		0.8	0.7	1.0	0.9	0.8	0.9	0.9
(corroded surface)		-	-	0.9	0.8	0.8	-	-

- = misleading due to severe corrosion
+ = could not be measured

Dating and technological evaluation of ring weave

The vast majority of all archaeologically found mail garments either stems from the wetland deposits from the Roman Iron Age (Germany and Denmark), from grave offerings in pre-Christian burials or from the mail garments of the 14^{th} and 15^{th} centuries in various collections. Apparently very little of the early Medieval ring weave material have survived. That is quite contradictory to the fact that it was during that particular period it saw its greatest use ever. The knights of the 12 – 14^{th} centuries were virtually clad in ring weave from head to toe. Contemporary depictions and written sources actually yield presents greater resources for the understanding of early Medieval mail garments than archaeological finds. The mass-graves dating from the Danish king Valdemar Attedag's conquest of Visby in 1361 make an important exception. I those graves large amounts of ring weave garments, coifs in particular, but there are some additional shirts as well. The contemporary depictions should be interpreted with a good deal of source criticism – artistic freedom, symbolism, misinterpretations, simplifications and travelling artists from other counties (for instance in church decorations) all altered the reality. But despite this the depictions are a valuable resource for which garments that were in use during specific parts of the middle ages.

Typological features in ring weave are hard to define, but some strains can still be traced. Since mail garments are often severely fragmentised it is of particular interest to find a way to determine their age from the appearance of the single rings. Many of the techniques used in the production of the ring weave have left traces that still can be observed on the rings. This assumption is based on Per-Olof Fredman survey over ring weave Swedish finds (Fredman 1992:23-55), my own observations and published surveys of, for instance some Danish, English and German finds.

The wire used for rings in most Iron Age finds was round, or almost round, in cross-section. This is the norm for both the riveted and the solid rings. From the latest part of the Viking Age (the 10^{th} century) and the beginning of the Medieval period the solid rings becomes more square or D-shaped in section. The solid, presumably punched, rings appear to be less pre-worked and rounded-off in cross-section than during earlier periods. A closer examination of the pre-Viking Age ring weaves also show a tendency towards D-shaped cross-sections. Single examples of D-shaped cross-sections with the flattest side turned towards the centre can be observed from finds from Roman Iron Age (Vimose and Thorsberg – Jouttijärvi 1996:54), and during the preparation of this paper the author himself examined a small fragment of ring weave dated to the Vendel period, the 7^{th} century (C 15968 – Oldsaksamlingen, Oslo).

Vaguely D-shaped/elliptical cross-sections could be observed on the solid rings. The areas around the rivets on riveted rings from the Iron Age, the Viking Age and the early Medieval period are marginally wider than the ring-wires proper and the rivets seem to be made mainly from round-sectioned wire.

Further along, during the Medieval period, the rivets were often flattened and wider in the rear ends. The rivet holes became more like slots than round holes. This gives the area around the rivet a characteristic elongated outline, often with a ridge-like tendency on the same side as the rivet head.

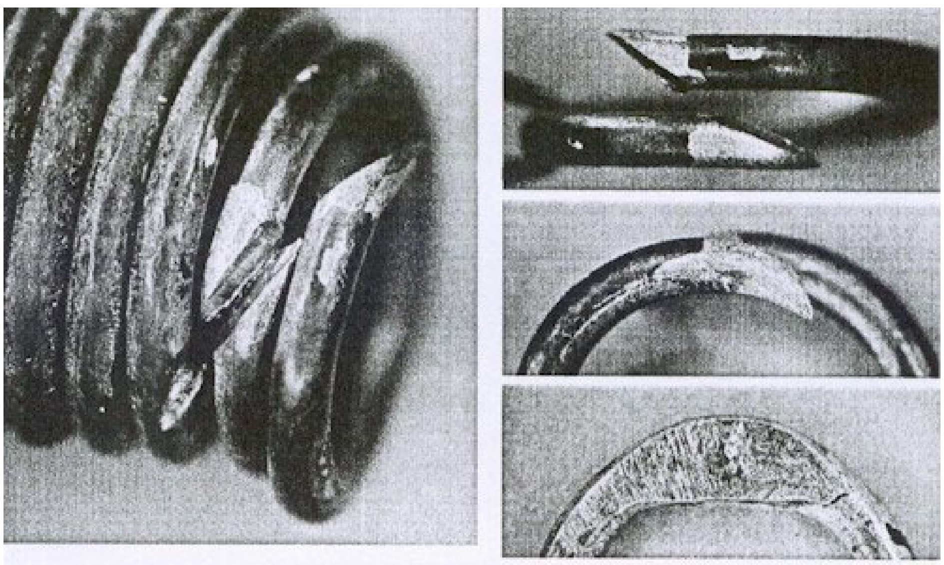
Normally the wire used for riveted rings was still fairly round in cross-section during the early Middle Ages. Riveted rings with flat or oval sections were not used to any greater extent until the 14th century. Riveted rings, flat or oval in cross-section are not necessarily a secure base for dating by themselves. But a late Medieval date is very probable if the same rings feature oblong rivet areas along with ridges on the same side as the rivet heads.

There are some extant examples of mail shirts with only riveted rings from as early as the Vendel Period (Fredman 1992:46), but they seem to be uncommon prior to the Middle Ages. The same type is very common during the 15th and 16th centuries, but it is not entirely prevailing (for concrete examples see Smith 1959:62-64). This might be due to the fact that the rivet is indeed the weak spot in the ring. Strictly speaking only half of the rings need to be open during the assembly, while the other half can be made solid and thus stronger. The extra strength is needed to provide protection against penetrating weapons like arrows and spears. Experiments with arrow-shooting on ring weave confirms this (Nielsen 1991:144). How laborious the manufacture of punched rings were in comparison with riveted rings is an interesting question, but it cannot be answered until thorough and repeated experiments with mail-making have been carried out. Production of solid rings by means of welding metal wire have been tried out and documented by some researchers (Smith 1959/60, Lang, Craddock, Hook 1992, O´Conner 1992).

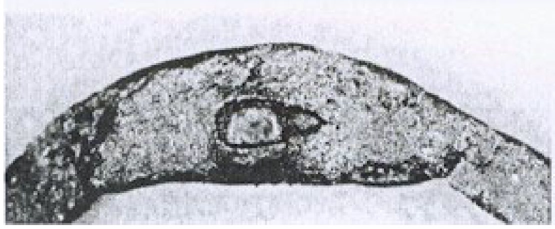
Riveted rings

All riveted rings from all times and in all types of mail garments show a consequent direction of the overlap – anti clock-wise. This is valid for all Norwegian finds examined by the author, but also for all the depictions and publications the author has been able to find. In principle they could as well overlap in the other direction. It might be caused by how the rings were made, and of the easiest way for a right-handed person to perform one or several stages in that process.

Almost all wire-ends on riveted rings are pointy by the overlaps. These pointy ends are normally slightly curved inwards, towards the centre of the rings. These features will appear if a coil of iron wire is wound on a metal rod and thereafter cut to rings by means of diagonal cuts with a chisel. If the coils are cut diagonally, following their curvature, the resulting rings will have a natural overlap and the "compression" suggested by Burges (1953) to create overlaps is completely unnecessary.



The result of the authors own attempt of diagonal ring cutting from red hot coil to attain ready-made overlaps.



An original ring showing signs of being cut diagonally, presumably performed as mentioned above.

The chisel could have been hand-held, but it would presumably be easier to control the cutting if it was attached to a stump or an anvil with the edge facing upwards. Such a tool is called a “hardie” by blacksmiths.

Rivet heads are often only visible on one side of the rings, but occasionally both faces show rivet heads. On those ring weaves where rivet heads are only visible on one face, the rivet heads always face in the same direction. On preserved garments they face outwards. Single exceptions do exist, but these garments have probably been turned inside-out.

Rivet heads are almost unexceptionally of a hemispherical outline, some flatter than others. No apparent facets left by hammer strikes can be observed on the rivets, not even on the oldest finds. Facets do appear on later repairs when rings have been added to existing ring weaves (Jouttijärvi 1996:54). The rivet heads don’t consist solely of the compressed rivet shanks, even when they have a perfect hemispherical outline. Some metal from the ring-wires is also incorporated in them. The extra metal probably originates in the edges that surround the exit holes as a result of these being punched with a pointy tool (See the analysis of C455 for pictures etc.).

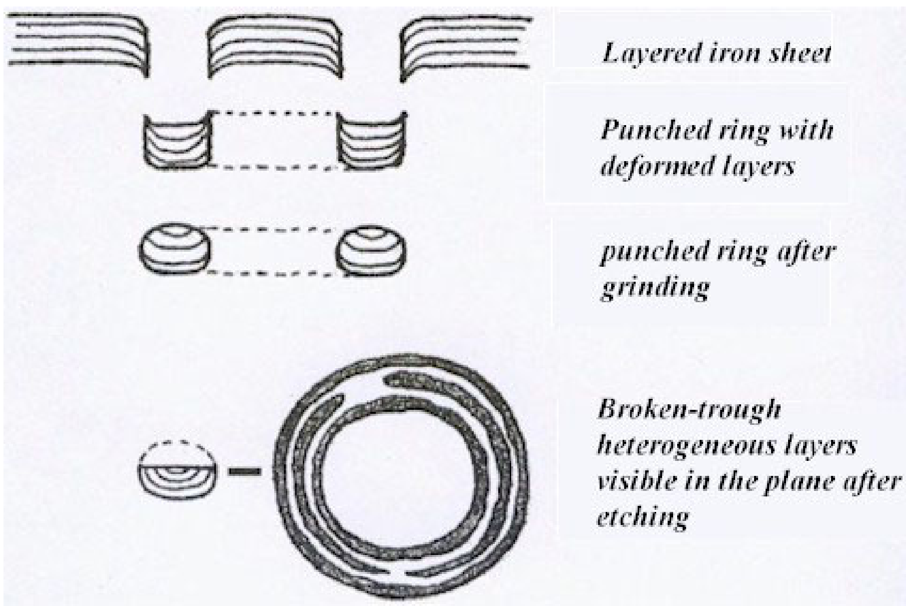
Hence the rivet heads ought to have been formed with some kind of swage, with a cavity, shaped like a negative of the rivet heads. The cavity would have been pressed towards the rivet by hammer strikes or by the force in the jaws of a pair of tongs (for an example – see the cover picture).

Onwards, during the Middle Ages, the riveted rings got more oval or flat in section. The sectional shape appears to be very regular (se C 455 – wire gauge). The same tool that was used to flatten the rings’ overlap could also have been used to flatten the rings.

Punched rings

The solid rings could have been produced with a stamp, or with two punches – one for the inner hole and one to separate the ring from its outer matrix. Several examples of such punched rings have been found. In this survey it could be established that the solid rings in both of the two mail shirts were produced by means of punching. Arne Jouttijärvi’s metallographical surveys from 1996 also showed that all examined solid rings were punched. Two other metallographical surveys that spoke in favour for welding as means of production for solid rings might not hold for a more thorough examination (Smith 1959/60 and Lang, Craddock, Hook 1992). The documentation of the ring weave from Coppergate is somewhat unclear when it comes to the supposedly welded rings.

A picture of a cross-sectional cut is featured in the publication (Lang et al 1992). In it heterogeneous layers and flattened ferrite grains in plane with the ring can be seen. These features all speak in favour for punching rather than welding. Dr Smith in terms studied a large number of mail shirts from the 15th and 16th centuries. He studied complete rings, and thus he lack evaluations of the rings build-up in section. Due to that he probably misinterpreted the latter – it seems like he confused observations of slag stripes with formations caused by layered, heterogeneous iron (ferrite/perlite). These layers are usually deformed by punching which causes them to be broken-trough in a plane grind, much like the grain in a wooden board. The result, after etching, will be visual stripes following the curvature of the ring.



The after-treatment of punched rings seems to have been made to remove burrs. In a German manual from the 15th century such a treatment of rings can be seen (Treue 1965:54 – text on p. 116 in the text volume).

Ring maker, 15th century (Treue 1965)

In it, many rings at a time are shown as mounted on a thick “bowstring”. They are grinded trough a bent track in a leather-lined wooden block. This goes well with the D-shaped (the straight edges facing inwards the centre holes of the rings) cross-sections of the ring-wires (earlier brought to light by Arne Jouttisjärvi 1996). Strike shaping of every single ring while it is thread on a metal rod is also a possible after-treatment (suggested by Burgess 1959/60; Sim:1998), but it is probably much more laborious. Solid rings with round cross-sections could theoretically have been treated with a set-hammer and a swage after being punched, as suggested for the Hedegårds shirt by Malfilâtre (1993:44).

Laborious production

If one considers that the making of a mail shirt demanded thousands of rings to be produced and assembled it is easy to understand that it was an enormously laborious process. Metal wire and thin iron sheets have to be produced. The wire would have to be wound into coils and solid rings would have to be punched out of the sheets. The coils would then have had to be cut to form overlapping rings and the raw, punched rings grinded to remove burrs. All the rings then had to be assembled according to the 4-1 pattern, so that each ring was connected to four others.

Then the rivet holes were made and the rivets riveted. Now and then the work had to be stopped and evaluated during the assembly, so that the garment attained the right shape.

Das Hausbuch der Mendelschen Zölfbrüderstiftung from the 15th century tell that it took half a year to make a mail shirt (Treue 1965). The mail shirt from Verdalen (C 455) is made up by approx. 27000 rings.

To shape a ring weave garment

Ring weave is a so-called isotropic material. It is assembled according to a pattern that is orientated in two directions, and it is more stretchable in one of these two directions. The most stretchable direction is always horizontally orientated in mail garments (see the preface). This is the norm for all mail shirts, with the exception for single early Roman and Celtic shirts – the Hedegård shirt is one of them (Malfilâtre 1993). The pattern run for the whole length of the sleeves on mail shirts, it is never altered to change direction by the shoulders. The laced mail hosen and the gorget from Møllerdalen (C 3250 & C 3108 – Oldsaksamlingen, Oslo) show the same features. The said orientation can be seen in connection to helmets as well, for example in finds from Vendel and Valsgärde (Arwidsson 193, 1939, 1942, 1954 and 1977) and from Coppergate (O´Conner et al 1992).

The sleeves on the mail shirt from Verdalen (C 455 – Oldsaksamlingen Oslo) are made more flexible by alterations in the ring weave under the armpits. The result is the same as with tailored shoulders on jackets and sweaters. The hosen from Møllerdalen (C 3250 – earlier interpreted as a sleeve) also feature subtle alterations in the pattern to give it a better fit. One example of these alterations can be seen in a gore up at the inside of the hosen's thigh-part. The gorget C 3108 has an extension to provide sufficient space for the chin. It also features overlapping edges on each side of the chin section, probably to allow the edges to be laced snugly to the latter when needed. This gorget is an uncommon artefact, and on stylish grounds it can be dated to the 15th century. The find was earlier interpreted as part of a sleeve. That is without doubt wrong. The gorget is intact and in a very good state of preservation (C 3108 – Oldsaksamlingen Oslo).

Chronological evaluations of the ring weave garments

In addition to the surveys on ring-level, the mail garments must be evaluated as garments. On lucky occasions both can be studied simultaneously – that is when complete garments can be made available to research. The find context, with more easily dated artefacts might be of some help when it comes to dating archaeologically found ring weave. Whole garments might be dated with the help of contemporary depictions or written sources. Such adaptations must be used with a great deal of source criticism though, since many types of garments were in use for several hundreds of years. Such iconographical comparisons could be interesting though if they are carried out along with evaluations on ring-level, for example the depictions on the decorative tinned pressings on Vendel Period helmets, on the Bayeux tapestry dated to the last part of the 11th century and on Norwegian altar frontals from the 13th and the early 14th centuries. The Bayeux tapestry show, among other things, early use of ring weave hosen. It is only Duke William him self and one of his close associates that are depicted as wearing such hosen. The ordinary knights are only shown wearing mail shirts with hoods.

Written sources as Beowulf, the King's Mirror, the early Scandinavian laws and the Hirdskraa all provide information on ring weave garments.

Conclusion

The limited material that was analysed in this paper cannot provide grounds for an all to conclusive interpretation, but the results fit well into the surveys on Danish ring weave performed by Arne Jouttijärvi. All the examined solid rings were punched and not welded. Ring weave made from solid and riveted rings on a 50-50 basis was more common than expected, on the expense of weaves where all rings were riveted. Some typological features on ring-level seem to be of significance for the dating of individual ring weaves, but the lack of finds from the first half of the medieval period renders large gaps in the typology. Generally speaking it seems like the production of ring weave was a particularly laborious and time-consuming craft. Special tools were used to shape the rivet holes and to perform the riveting, most probably long before the Middle Ages. The drawing of metal wire seems to have been a craft that was closely associated with mail making, but this paper does not attempt to make any in-dept survey of that part of the process. It could not be answered whether the wire was drawn by the mail maker him self, or by other more specialized craftsmen. An attempt to answer the latter question is one of the ways to pinpoint the mail maker's position in, and interaction with, his surrounding society.

The more symbolic aspects of ring weave, along with its use and efficiency in battle have not been evaluated above. They might be the main topics for forthcoming studies.

Ordliste

Senke	Verktøy med en gropform som metallet kan bankes ned i for å få et avtrykk av gropens form.
Kjeft, tang med.	Det området av en tang som brukes til å holde ting fast
Metallografi	Sliping og polering av en metallflate for å i mikroskop kunne studere sammensetning og strukturer som har oppstått i metallgjenstandens fremstilling.
Brynjevev	Betegnelse på fleksibelt materialet som oppstår når metallringer hektes sammen i et bestemt mønster. Brukt i Europa som rustningsmateriale mellom ca 300 ff kr. og opp i middelalder for å beskytte mot kuttskader.
Stuke	Det å gjøre en bolt eller stang tykkere i enden.

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