Acta Militaria Mediaevalia IX
Kraków – Rzeszów – Sanok 2013, s. 203-229

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A NOTE ON THE CONSTRUCTION AND METALLURGY OF MAIL ARMOUR EXHIBITED IN THE WALLACE COLLECTION

Abstract:

Edwin Wood, David Edge, Alan Williams 2013, A note on the construction and metallurgy of mail armour exhibited in The Wallace Collection, AMM IX: 203-229

An exhibition was mounted in 2009 at the Wallace Collection, London, displaying a number of mail shirts and other garments. The number of rings used in several of these mail shirts has been accurately determined for the first time. Mail can be "tailored" that is, its shape can be altered, by varying the number of links attached to each one from 4 to 3 or 5, thus contracting or expanding the weave. The "tailoring" of several shirts has been mapped, and the thickness of the links in different parts of the garments compared. Selected links have been studied by metallography, and deductions made about the heat-treatment of the completed shirt.

Key words: Mail, hauberk, voider, coif, mailmakers' names, wire thickness, mail tailoring, medieval iron and steel

Introduction

The impetus for this paper came from an exhibition of mail armour in 2009 at the Wallace Collection, London, which drew upon items from this collection as well as many others from a private collection. As part of our studies of mail, two of the authors travelled to Prague to examine the mail shirt of Sv. Vaclav (St. Wenceslaus) and an account of which has been published in this journal (Checksfield, Edge, Williams 2012).

The origins of mail

The origins of mail armour, that is, armour formed of interlinked metal rings, remain an issue of debate. The Roman writer Varro, in his work on the origins of words attributed its invention to the Gallic peoples to the North: *Lorica quod e loris de corio crudo pectoralia faciebat; postea subcidit gallica e ferro sub id vocabulum, ex anulis ferrea tunica*[1].

The oldest fragments of mail yet found came from Romania from a grave dated to the 3rd c. BCE. M. Rusu (1969) shows what appear to be both riveted and welded links of circular cross-section. Most of the links were of wire between 0.8 and 1.8 mm thick and were between 8.5 and 9.2 mm in diameter. There also were rows of butted links, which may have been a repair. Mail might have developed from protective garments made up of rings threaded onto cords, like netting; a fragment of such a garment was found in a much earlier Celtic grave in Bohemia, perhaps of the 8th c. BCE (Hrubý 1959, 33).

Certainly if it was a Gallic invention then the Romans can be credited with taking the technology and spreading it across Europe, the Middle East and North Africa. Mail was the predominant armour used by the Roman legions of the Republican period and remained prominent throughout the Empire's existence. The ease of its manufacture and the way that it lent itself to mass production certainly contributed to its popularity when labour was cheap. The almost infinite reparability of mail would contribute to long years of service, with mail coats, or their elements, remaining in use for many centuries.

It is believed that Roman mail was largely constructed using welded and riveted rings in alternate rows, though much mail from this period is heavily corroded and so analysis is not easy.

1 *The "lorica"* [is so called because] *they used to make chest armour from thongs of rawhide, and later the Gallic one of iron, an iron tunic of little rings, was included under this name*.

Fig. 1. A1 mail from The Wallace Collection: 1 – front; 2 – back (Copyright Trustees of The Wallace Collection).

Ryc. 1. Kolczuga A1 ze zbiorów The Wallace Collection: 1 – przód; 2 – tył (Copyright Trustees of The Wallace Collection).

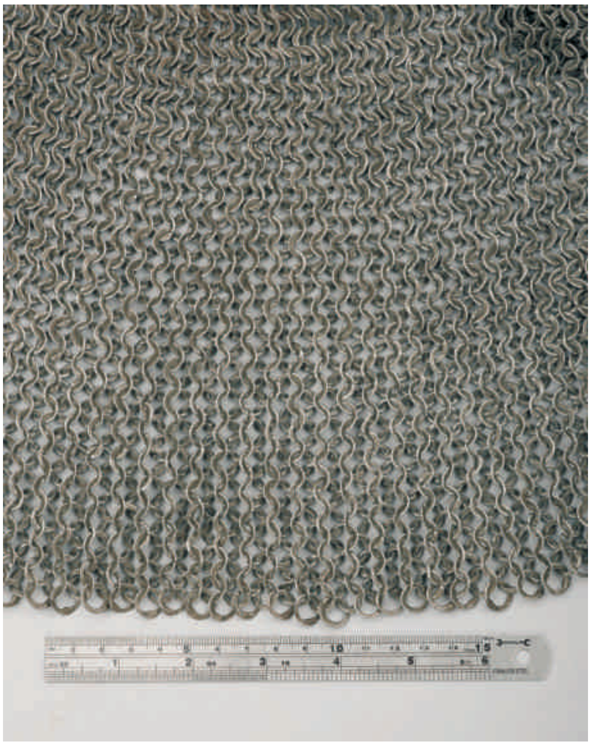

Fig. 2. A1 mail from The Wallace Collection – detail interior (Copyright Trustees of The Wallace Collection).

Ryc. 2. Kolczuga A1 ze zbiorów The Wallace Collection – zbliżenie partii wewnętrznej (Copyright Trustees of The Wallace Collection).

Fig. 3. A1 mail from The Wallace Collection – maker's ring (Copyright Trustees of The Wallace Collection).

Ryc. 3. Kolczuga A1 ze zbiorów The Wallace Collection – ogniwo z marką wytwórcy (Copyright Trustees of The Wallace Collection).

The pattern that is traditionally associated with the *lorica hamata* is that of a sleeveless tunic with shoulder doublings for added protection in this vulnerable area. In many ways it is simply a replication in metal of the linen cuirass used by the Greek hoplite, which was also the armour used in the early years of Roman history. It is probable that by the early 2nd c. BCE the mail coat had been given

Fig. 4. A2 mail from the Wallace Collection: 1 – front; 2 – back (Copyright Trustees of The Wallace Collection).

Ryc. 4. Kolczuga A2 ze zbiorów The Wallace Collection: 1 – przód; 2 – tył (Copyright Trustees of The Wallace Collection).

Fig. 5. A2 mail from The Wallace Collection – detail (Copyright Trustees of the Wallace Collection).

Ryc. 5. Kolczuga A2 ze zbiorów The Wallace Collection – detal (Copyright Trustees of The Wallace Collection).

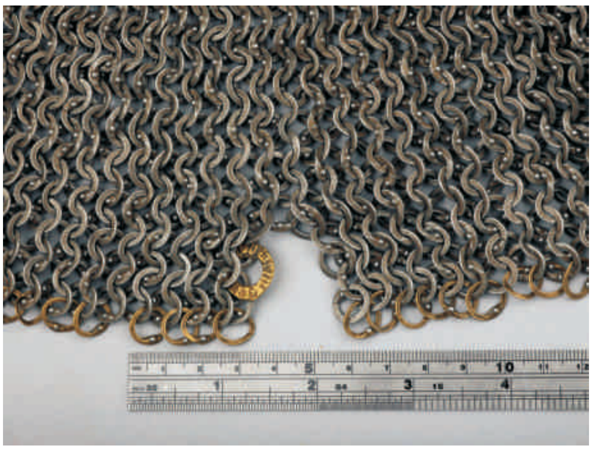

Fig. 6. A2 mail from The Wallace Collection – detail with maker's ring (Copyright Trustees of The Wallace Collection).

Ryc. 6. Kolczuga A2 ze zbiorów The Wallace Collection – detal z ogniwem (marką) wytwórcy (Copyright Trustees of The Wallace Collection).

sleeves and the shoulder doublings removed as the need for greater arm protection was appreciated.

Certainly if we are to believe the Roman sources it was in the late 1^{st} c. CE that Domitian introduced the arm defence of segmented plates, *manica*, as standard equipment. The use of this defence by gladiators is well attested long before this date and so it is possible that it had been in use for some time before Domitian's innovation.

Fig. 7. A3 mail from The Wallace Collection – threequarters view (Copyright Trustees of The Wallace Collection).

Ryc. 7. Kolczuga A3 ze zbiorów The Wallace Collection – widok w ujęciu trzy czwarte (Copyright Trustees of The Wallace Collection).

Fig. 8. A3 mail from The Wallace Collection – detail of neck (Copyright Trustees of The Wallace Collection).

Ryc. 8. Kolczuga A3 ze zbiorów The Wallace Collection – szczegóły kołnierza (Copyright Trustees of The Wallace Collection).

By the mid 2nd c. CE the mail hauberk as it would come to be known had come into being. This was a shirt of around mid-thigh length with wrist length sleeves. The finds from Dura Europos in Syria include a mail shirt of this type, attributed to a Persian soldier though it may have been taken in one of the innumerable skirmishes fought in that area (James 2004, 116-120 – mail, 120-139 – scales, etc). The fluid situation along the Roman borders means that mail found in those regions might have been either Roman or 'barbarian' in origin. This is especially true in areas such as the Rhine where more and more native troops were being used to defend the borders. *Foederati* tribes might wear their own equipment but no doubt also employed the best that Rome had to offer. Roman troops did the same, employing native tactics and equipment until Roman legions and *foederati* troops could scarcely be distinguished from one another any longer.

Thus the use of mail was spread throughout the Roman world and beyond, and what had distinguished the early legions from their foes, namely their armour and discipline, was no longer applicable to the later enemies of the empire. They had learned from the Romans by wearing armour and adopting more disciplined tactics at the same time as the Romans had grown complacent.

Little mail of this period survives intact, most complete shirts dating from the 11th c. or later, while the Thorsberg material is one of the few exceptions to this.

An account of the finds from the peat bogs (or mosses) such as Thorsbjerg and Nydam was published by the Danish archaeologist responsible (Engelhardt 1866). Dendrochronology has now ascribed a date of 320 CE to the timbers of the Nydam boat (Guratzsch 2002, 143). No human remains were found in Thorsbjerg, but the remains of mail shirts instead. Five or six very corroded hauberks (mail shirts) were found rolled up, and in two cases they had been placed inside clay vessels. Two of the larger fragments were made of round section wire, and rows of riveted & welded links alternate, one of which was made of 10 mm, the other of 9 mm diameter rings. In one instance, the rivets were of bronze. In addition, strips of mail made up of bronze rings were also found. These were presumably borders from the hems of mail shirts.

At Vimose (Engelhardt 1869) there was one fragment of mail which was made of links apparently flat in section and alternately riveted and welded. Another, very damaged, was round in section, and consisted of two parts attached to both sides of a bronze hinge (75 mm high), presumably part of a body armour. These had been deposits into a "sacred lake" which gradually filled up with vegetation, and hence a layer of peat formed, and the lake became a moss.

Fig. 9. A6 mail (associated with A20) from The Wallace Collection – threequarter view (Copyright Trustees of The Wallace Collection).

Ryc. 9. Kolczuga A6 (połączona z A20) ze zbiorów The Wallace Collection – w ujęciu trzy czwarte (Copyright Trustees of The Wallace Collection).

Fig. 10. A7 mail from The Wallace Collection – threequarter view (Copyright Trustees of The Wallace Collection).

Ryc. 10. Kolczuga A7 ze zbiorów The Wallace Collection – w ujęciu trzy czwarte (Copyright Trustees of The Wallace Collection).

Mail from this period seems to have followed the Roman practice of using a mix of welded and riveted rings, although one may postulate that this is because much Roman mail survived the end of the Roman Empire and was maintained for centuries with adjustments and repairs. The continual reuse and repair of Roman mail may also go some way to explaining the apparent disappearance of all the mail issued to the Roman legions in the final centuries of the Empire.

In Western Europe the disintegration of the Roman Empire led to a prolonged period of instability. The Early Medieval period saw the development of numerous small states and permanent standing armies were replaced by a small elite warrior class, augmented by local levies. In Northern Europe and Scandinavia warriors fought on foot in dense "shield walls" and protected by mail, for those who could afford it. The production of armour was an expensive business, as the amount of time and material that a mail shirt required would have made it a high status item.

Fig. 11. A7 mail from The Wallace Collection – detail of hem decoration (Copyright Trustees of The Wallace Collection).

Ryc. 11. Kolczuga A7 ze zbiorów The Wallace Collection – szczegóły dekoracji dolnej krawędzi (Copyright Trustees of The Wallace Collection).

By the 11th c. mounted knights clad in mail had become common on the battlefields of Western Europe. The *Bayeux tapestry* demonstrates clearly the central role of the mailed knight in Norman armies. Such was their success that it allowed the Normans to conquer Naples and Sicily, as well as England, and lead the recapture of Jerusalem.

Mail production in the Middle Ages was to become an extensive industry, although the deficiencies of mail in protecting against missile attacks led to an increasing use of reinforcing plates (Williams, Edge 2004, 123-134). As it became easier to produce plate metal in greater sizes and better quality then the mixture of mail and plate armour evolved by the 15th c. into the complete suit of plate (or "harness") with only a little mail to protect the joints between the plates. "Voiders" were portions of mail designed to protect the armpits when a knight raised his sword-arm to strike.

Much of the good quality mail surviving today dates to the 15th and early 16th c., even though it was no longer the principal element in armour. It is from this period that much of the data in this paper will come, and some of this mail carries rings stamped with the name of the town where the workshop was located or even what may have been the maker's name.

The Construction of Mail Armour

The number of rings used in a mail garment has never heretofore been accurately recorded, although estimates have varied from 15,000 to more than 40,000. So for this paper the task of accurately recording the number of rings in a variety of garments was undertaken by one of the authors (EW).

The process by which mail was counted is simple; using marker rings the garment is divided up into blocks of known size, 10x10, 20x10, 20x20, etc. These areas can then be counted up and multiplied to produce the result. Any areas that do not fit into the system of neat blocks, and there are many, are simply counted by hand and added to the total. Thus the number of rings can be determined with accuracy and within a reasonable time (Table I and II).

Inventory number	Type of Garment	Possible date (c.)	Figures	Number of Rings
A1	shirt (hauberk)	15th	1-3	25,419
A2	shirt	15th	4-6	26,941
A3	shirt	15th	7-8	29,653
A7	shirt	16th	10-11	147,706
A8	cap	15th	12, 39	6,607
A12	sleeve	16th	13, 15	18,043
A14	sleeve (Left)	16th	14, 17	13,977
A15	sleeve (Right)	16th	16	22,267
Oa1886	Oriental mail coat	18th/19th	18	218,128

Table I. Items of mail from The Wallace Collection.

Tabl. I. Okazy pancerzy kolczych z The Wallace Collection.

Inventory number	Type of Garment	Possible date (c.)	Figures	Number of Rings
RW1	shirt	14th/15th	19-20	32,725
RW sleeve 1	sleeve	14th	25	7,702
RW sleeve 2	Voider (with reinforce)	15th/16th	26	21,166

Table II. Items from the Private Collection.

Tabl. II. Okazy pancerzy kolczych ze zbiorów prywatnych.

Fig. 12. A8 mail cap from The Wallace Collection – front (Copyright Trustees of The Wallace Collection).

Ryc. 12. Kaptur kolczy A8 ze zbiorów The Wallace Collection – przód (Copyright Trustees of The Wallace Collection).

Fig. 13. A12 sleeve from The Wallace Collection – front (Copyright Trustees of The Wallace Collection).

Ryc. 13. Rękaw kolczy A12 ze zbiorów The Wallace Collection – przód (Copyright Trustees of The Wallace Collection).

Fig. 14. A14 sleeve from The Wallace Collection – front (Copyright Trustees of The Wallace Collection).

Ryc. 14. Rękaw kolczy A14 ze zbiorów The Wallace Collection – przód (Copyright Trustees of The Wallace Collection).

Fig. 15. A12 sleeve from The Wallace Collection – detail copper alloy links (Copyright Trustees of The Wallace Collection).

Ryc. 15. Rękaw kolczy A12 ze zbiorów The Wallace Collection – zbliżenie na mosiężne ogniwa (Copyright Trustees of The Wallace Collection).

Fig. 16. A15 sleeve from The Wallace Collection – front (Copyright Trustees of The Wallace Collection).

Ryc. 16. Rękaw kolczy A15 ze zbiorów The Wallace Collection – przód (Copyright Trustees of The Wallace Collection).

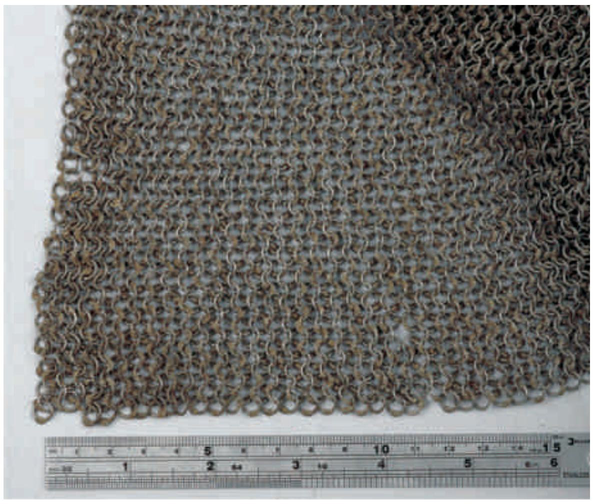

Fig. 17. A14 sleeve from The Wallace Collection – detail exterior links (Copyright Trustees of The Wallace Collection).

Ryc. 17. Rękaw kolczy A14 ze zbiorów The Wallace Collection – zbliżenie zewnętrznych ogniw (Copyright Trustees of The Wallace Collection).

The 12 mail garments listed above allow a number of averages to be inferred. A waist-length mail shirt with rings of approximately 7 mm internal diameter and half- to full-length sleeves, will have on average 28,685 rings. Mail of smaller internal diameter has proportionately more rings, so mail of 5-6 mm will increases the number of rings, and the shirt A7 has nearly 150,000 rings. It may be postulated that a Roman mail coat of the Republic might have had between 20,000 and 50,000 rings, as while it lacked sleeves, it would have been longer and had doubling on the shoulders.

The Indian mail coat OA1886 with a ring diameter of approx 3 mm, which is typical of much late Oriental mail, has a ring count nearing 220,000, and longer oriental coats would have had even more.

The voider is approximately rectangular in shape and has a square reinforce of much more closely woven rings in the centre of the rectangle, so as to give more protection to the wearer (see Figs 21-22).

E. M. Burgess (1953a, 48-55; 1953b, 193-201) briefly noted in his work on A2 that the mail seemed to be slightly thicker at the top of the shirt than at the bottom, so it was decided to study this in more detail.

The division of the mail into small units allows for a program of investigation into the material used. The measurement of ring thicknesses within each block of 100 can provide an average for the wire used in that group.

This average was then plotted onto a simplified map of the mail item so that it could be determined whether this was a deliberate pattern, or a random variation. The front areas of three shirts (A2, A3 and RW2) were examined in detail, while examination of the back was performed less rigorously. It was observed on all three shirts that the mail at the top of the shirt was made of thicker wire than that at the bottom. On A2 the maximum decrease in thickness from the rings at the top to rings at the bottom hem is 1 mm. In the case of A3 there is a decrease of at least 0.5 mm and in the case of RW2, there is a maximum decrease of 0.7 mm (see Chart 1).

The potential reasons for employing such a pattern of construction are many. Firstly the reduction of the wire gauge would reduce the weight, allowing the areas that require high protection, the shoulders and upper torso, to be better protected while the lower torso, an area less likely to be struck, could make do with thinner wire. The reduction in weight has two benefits; firstly it makes it easier for the wearer to carry and thus makes fighting easier, secondly it means that wear is reduced on the upper rings and so damage to the mail is less likely to occur through rings breaking under stress. The construction of mail in this way shows a high level of skill in its construction, it was not a uniform product of unskilled labourers. These mail coats were constructed with considerable forethought to suit them to the wearer. How this was achieved without increasing the time taken to make a mail shirt is debatable. It is quite possible that mail was made as patches each made up of rings of different gauge. These patches could then be rapidly assembled to make a shirt as required. The open fronted shirt (RW1) also follows this pattern: it has thickened patches in the area of the thigh, something useful for a mounted soldier as this area is more vulnerable to attack.

Tailoring

Mail was designed to be worn in combat and therefore needed to be as flexible as possible in order to help keep the wearer alive. Producing mail to fit the wearer closely would have greatly increased its effectiveness by reducing excess weight, and so make movement in combat much easier and swifter. It has been known for some time that mail can be "tailored" and Burgess previously described this in the shirt A2.

The term "tailoring" is used here to cover alterations in the mail weave by the addition or subtraction of rings. An "expansion" is a vertical alteration that involves adding an 'idle' ring to the normal 4-1 pattern, this ring is then used in the row below to add an extra ring and so broaden the weave (Fig. 27:1). A "contraction" is effectively an expansion rotated upside down, so that it appears as 3 rings being drawn into one in the row below, thus removing one ring from the breadth of the weave (Fig. 27:2). Horizontal tailoring of the weave, "row removals", occur normally in the arms, but can be found around the bottom edges of mail coats. There are two main methods of performing this tailoring, the first is to simply stop two rows and pull together the ones above and below, though this normally leaves a hole in the weave (Fig. 28). The second is by forming a 'knot' by which the hole that would be created by the above method is closed by using idle rings to pass through several rows (Fig. 29).

Burgess' pioneering paper demonstrated a clear pattern in the construction of shirt A2 (Fig. 30). Expansions occur over both of the shoulders (18 in total), nine over each shoulder. This would allow for the fact that the back of a man is broader than the front and also provide a freedom of movement

Fig. 18. OA1886 mail from The Wallace Collection – front (Copyright Trustees of The Wallace Collection).

Ryc. 18. Kolczuga OA1886 z The Wallace Collection – przód (Copyright Trustees of The Wallace Collection).

Fig. 19. RW1 mail – front (Copyright Trustees of The Wallace Collection).

Ryc. 19. Kolczuga RW1 – przód (Copyright Trustees of The Wallace Collection).

for the arms. This additional mail is removed from below the shoulder blades by a series of 18 contractions in the mail, two groups of nine that converge in an incomplete 'V' shape on the back. These contractions pull in the mail around the waist so reducing the bagging about the stomach. This is assisted by the addition of eight more contractions; four on the back and four on the front, and each group of four is formed into a square. The mail is therefore drawn in and its weight reduced; its close fit also means that the mail is less likely to sweep about and be an inconvenience during movement. To accommodate the hips there are four sets of nine expansions set at quarters around the lower section of the hauberk. There are also two knots set upon opposing sides of the shirt at hip height, these serve to make the back of the mail longer than the front.

This paper will now discuss six more hauberks (mail shirts) and contrast them with A2. Three of these are from the Wallace Collection, namely A1, A3 and A7. The catalogue suggests that A2 and A3 date from the 1st half of the 15th c., while A7 is described as a 16th c. shirt (Mann 1962). A3 has long sleeves, unlike A2 which has elbow length sleeves. It is quite similar in the size of its rings and their closure to A2, though it lacks any latten

Fig. 20. RW1 mail – stamped ring (Copyright Trustees of The Wallace Collection).

Ryc. 20. Kolczuga RW1 – ogniwo z marką wytwórcy (Copyright Trustees of The Wallace Collection).

edging or an inscribed ring. Both garments contain a relatively similar number of rings. The other three are from a private collection and were loaned to the Wallace Collection for their exhibition. All the mail discussed here is of the ‘all-riveted’ variety, whereby each of the rings is individually closed using small rivets, which in all these cases were wedge shaped.

The first of these, shirt RW1, is a “double-breasted” shirt of open front design (Fig. 19). The shirt resembles a jacket and can be put on like one; the front is then overlapped to double the chest protection. The shirt also has wrist length sleeves and is relatively long in the back reaching almost to the upper legs. The ragged mail at the bottom hem suggests that it was possibly damaged in antiquity. The shirt carries an edging on the cuffs and the neck of latten (a medieval copper alloy) rings, and in addition it also carries a stamped ring (Fig. 20) set into the right hand collar of the neck – bearing letters which might be speculatively interpreted as connected with the name Wilhelm.

The second loaned shirt (RW2) carries a ring with the words Hans Muncher (perhaps the name Hans of München?) on it, and resembles A2 and “A3 in shape and size, though apparently signed by a different maker (Figs 21-22).

The third loaned shirt examined but not exhibited (RW3) is very similar to the others, and has a stamped link set into its collar which carries unintelligible gothic letters (Figs 23-24).

The method used to map the tailoring of the mail was taken from Burgess’ paper (1953), marking expansion and contractions with symbols attached to rings. Expansions marked with a copper triangle pointing upwards, contractions marked with a copper triangle pointing down. This is a simplification of Burgess’ own system but serves adequately to illustrate the pattern used in the construction.

Tailoring in shirt A3

In A3 there are expansions over the shoulders of the mail, eight upon each side compared to nine in A2. There is also the incomplete ‘v’ shaped contraction pattern from the bottom of the shoulder blades to the lower back. Made up of sixteen contractions, eight per side, this counters the shoulder expansions. Missing from this shirt are the two sets of four contractions on the front and back for pulling the waist in further. The shirt retains the four sets of expansions set at quarters about the hips to allow for movement and not restrict the legs (Figs 31-32). However, instead of there being nine expansions in each set there are only four. Where A3 differs considerably from A2 is in the length of its sleeves. A3 offers full protection to the arms, much like the shirt RW1, and features tailoring upon the sleeves. Construction of mail sleeves to fit the wearer is more complex than the making of a simple tube, since any excess mail on the arm would be an inconvenience. The mail must be contracted from the armpit using row-removals to narrow the arm. A3 also has elbow joints.

Elbow joints are put in to facilitate easy bending of the arm. They are marked out by a substantial number of expansions that run from the inside of the arm to converge at the elbow, so forming a “bag” of mail that hangs loose when the arm is held out straight but is pulled tight when the elbow is bent. These then require contractions to slim the arm back down along the forearm. The wrists are often given expansions to flare the mail over the hand; they are found in RW1 but not in A3.

Tailoring in shirt RW1

The shirt RW1 (Fig. 33) shares many characteristics with A2 and A3. This shirt is longer than either A2 or A3, and therefore contains more rings, in fact 32,725. It is very like A2 in design, having groups of nine expansions over the shoulder and also in the back contractions. There are however, in addition, a series of nine contractions that run vertically between the two usual ‘v’ sets, down the spine. These were most likely put in to counter the open fronted nature of the shirt, preventing the closing of the front from opening up the weave on the back too much. This series of contractions replaces the set of four that are present in the back of A2.

The set of contractions found on the front of A2 are absent because the shirt RW1 is open fronted. Like A3 the shirt RW1 has long, wrist-length, sleeves. It does not, though, have the elbow expansions seen in the former. Instead there is only a row of contractions from the armpit and expansions at the wrist to flare the cuffs. On the body of the shirt two sets of expansions are located under the arms to help prevent tearing in the armpit when the arms are raised. Around the bottom edge of the shirt are a series of row contraction knots that allow the hem to form a graceful curve up towards the front, rather than stepping the rows inward.

Tailoring in shirt RW2

The shirt RW2 when examined shows a tailoring pattern similar to A2; in fact it is

Fig. 21. Hans Muncher RW2 mail – front. *Photo by E. Wood.*

Ryc. 21. Kolczuga RW2 (Hansa Munchera) – przód. *Fot. E. Wood.*

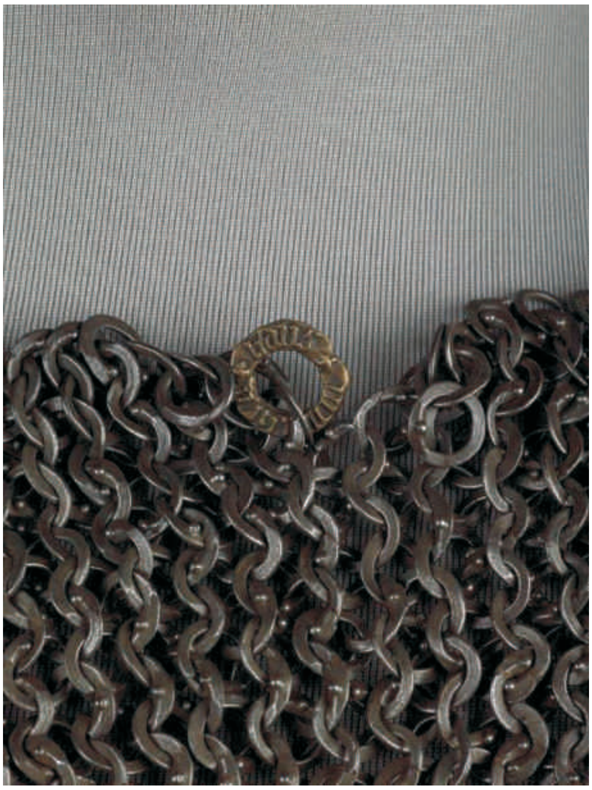

Fig. 22. Hans Muncher RW2 mail – stamped ring. *Photo by E. Wood.*

Ryc. 22. Kolczuga RW2 (Hansa Munchera) – ogniwo z marką wytwórcy. *Fot. E. Wood.*

Fig. 23. RW3 mail – threequarter view. *Photo by E. Wood.*

Ryc. 23. Kolczuga RW3 – w ujęciu trzy czwarte. *Fot. E. Wood.*

Fig. 24. RW3 mail – stamped ring. *Photo by E. Wood.*

Ryc. 24. Kolczuga RW3 – ogniwo z marką wytwórcy. *Fot. E. Wood.*

so similar that the two are almost twins. It has 8 expansions over the left shoulder and 9 over the right shoulder; these are countered by two sets of 9 contractions in the now familiar 'V' shape down the back. Like A2 it has the additional set of four contractions set in a square mid way between the two main sets of contractions, this is matched by 4 contractions on the front of the shirt, as with A2. Under each of the arms there

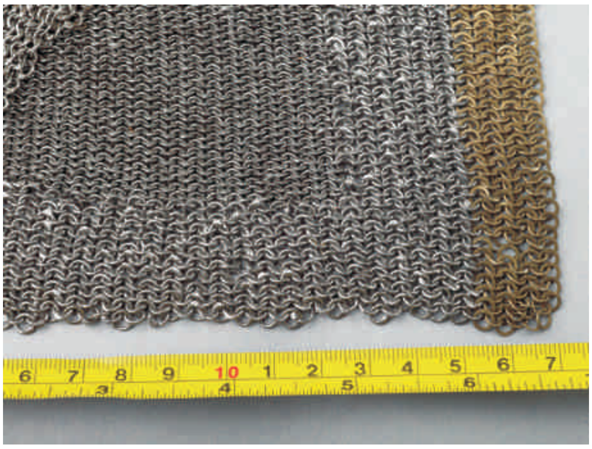

Fig. 25. RW voider 1 from private collection with reinforce detail (Copyright Trustees of The Wallace Collection).

Ryc. 25. Łącznik kolczy RW z widocznym wzmocnieniem, kolekcja prywatna (Copyright Trustees of The Wallace Collection).

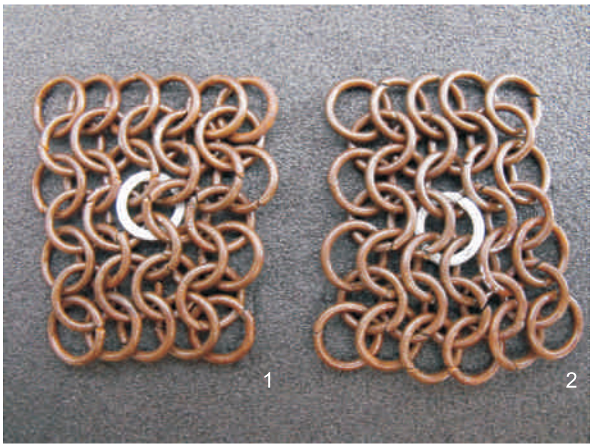

Fig. 27. Tailoring of mail: 1 – expansion; 2 – contraction. *Photo by E. Wood.*

Ryc. 27. Dopasowywanie kroju kolczugi: 1 – poszerzenie; 2 – zwężenie. *Fot. E. Wood.*

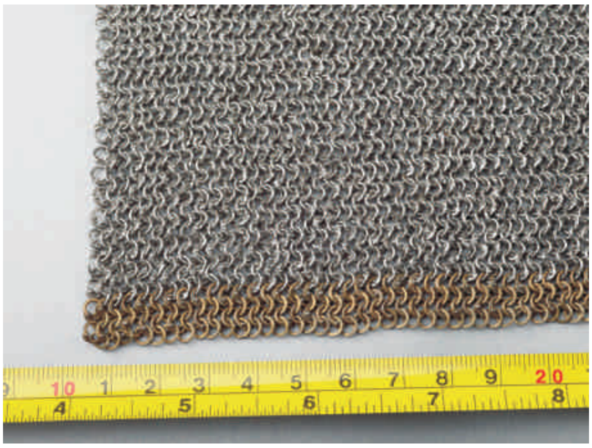

Fig. 26. RW voider from private collection without reinforce detail (Copyright Trustees of The Wallace Collection).

Ryc. 26. Łącznik kolczy RW bez wzmocnień, kolekcja prywatna (Copyright Trustees of The Wallace Collection).

Fig. 28. Tailoring of mail – row removal. *Photo by E. Wood.*

Ryc. 28. Dopasowywanie kroju kolczugi poprzez usunięcie rzędu ogniw. *Fot. E. Wood.*

are 6 contractions, as seen in RW2. The hips of the shirt are flared by four sets of 9 expansions running from the waist down at quarter points around the body, as with A2.

This might suggest that they share a common origin, and perhaps a similar date of manufacture. Another shirt that shares this same tailoring pattern was again examined by Burgess in 1958, when it was part of the Hearst collection. It is now also in the Royal Armouries. It too had the shoulder expansions and contractions on its back, along with many other similar features. Burgess concluded that it belonged *to the same tradition as the Ernart Cowein shirt*, that is, A2 in the Wallace Collection (Burgess 1958, 197-204).

Fig. 29. Tailoring of mail – "knot". *Photo by E. Wood.*

Ryc. 29. Dopasowywanie kroju kolczugi – „węzeł". *Fot. E. Wood.*

Tailoring in shirt RW3

The shirt RW3, also seems at first sight to belong to this tradition. However, there are some interesting differences. There are two sets of 11 expansions over the shoulder, countered by two sets of 11 contractions in the 'V' shape. Set at the quarter points there are 4 sets of 8 expansions to make room for the hips. However, instead of there being a close group of 4 contractions on the mid point of the back and front, there is another smaller 'V' shape made up of 6 contractions between the shoulders and 4 on the front of the shirt at the top of the sternum. The pattern of this shirt may represent a transitional style between the mail discussed above (A2, A3, RW1, RW2) and the shirt A1 from the Wallace collection.

Tailoring in shirt A1

A1 does not conform to the style of construction utilised in those four shirts aforementioned. The contractions that run down the back form a triangle, made up of only ten contraction points (Fig. 34). This is significantly less than the numbers in the back contractions of A2, A3 and RW2; in addition to this there are only single expansions on each shoulder. Instead of expanding over the shoulder the upper chest and shoulders are made deliberately broad. To counter this from the underarm to the waist run a series of contractions eight in total, with a further two deep under the sleeve (Fig. 35). There are only three groups of expansions for the waist, at the front and sides, none on the back. The central front group contains twelve expansions, the left hip has eight expansions and the right hip nine (Fig. 36).

The shirt A1 is shaped to fit a man with a large upper body and very wide shoulders. Whether the pattern used reflects a different regional style, o r simply a unique adaptation to one individual's needs is unclear. It is sufficiently different to make it clear that this is not a mere adaptation of the pattern seen in the other three hauberks. Reid and Burgess examined a shirt similar to A1 from "Westwale" (Westphalia) in 1960. This shirt, now in the Royal Armouries, carries three inscribed rings, one with the name of the maker (Bertold), the second with the name of the town (Iserlohn) and the third a large talismanic ring. The overall pattern of tailoring is very similar to that of A1. While there are several differences, in general it has more in common with A1 than any of the other patterns seen here. It has V-shaped contractions at the top of the back, just one or two shoulder expansions, and large numbers of contractions under the arms (Reid et al. 1960, 46-57). The talismanic ring found on the shirt shares some similarities with that found on A1. The ring from the "Westwale" shirt was made from copper alloy and that from A1 is made from ferrous metal but the pattern stamped on them both is quite similar. Whether this may indicate a common origin is a question that requires further investigation.

Tailoring in shirt A7

This differs significantly from the other mail shirts discussed above. The rings are smaller and finer, totalling some 147,706. The arms are of wrist length and this shirt has a collar, made up of thickened rings to protect the throat, as well as copper alloy edging around the neck, cuffs and hem. Expansions occur over the shoulders where the collar joins the main body of the shirt, 12 upon each side. These are not countered on the back by any contractions, unlike those of A2, A3 or RW2. This may be because the use of smaller rings in the weave makes a garment more conformable to the body. There are further expansions in the sleeves, at the elbow (like A3), to accommodate freer movement of the arms. There are also a row of contractions running down the upper arm and picking up again after the elbow bag to pull the mail closely in down the forearm.

Shirt A7 demonstrates a tailoring method that is significantly different to the five other examples (Fig. 37). Because it seems to be a later garment it was perhaps intended for civilian, rather than battlefield, use. This might mean that it would not require the close fit needed for combat armour, or that mail of such size fitted closely enough without the tailoring necessary for garments with larger ring sizes.

Mail of similar ring size to A7 is also found in the sleeves (A12, A14 and A15) and the mail cap (A8) and is thought to be 15th c.. The sleeves certainly display methods of construction paralleling those used in the sleeves of A7, and in some ways those of A3 (Fig. 38).

Tailoring in cap A8

The mail cap, A8, utilises similar methods of expansion to those found in the elbow joints of A3 to bring together the four pieces that make up the skull of the cap. Formed effectively of four triangular pieces of mail that have been joined together to form what would, if supported, make a pyramid. This cap A8 is not constructed in a way normally used to make coifs. On first inspection it is a method of construction that does not seem logical; however, when utilised properly the method is effective. It is tempting to wear the cap with the central point on top of the skull, yet this drapes mail over the eyes and causes the sides to

Fig. 30. Tailoring in A2 mail from The Wallace Collection – back. *Photo by E. Wood.*

Ryc. 30. Krój kolczugi A2 z The Wallace Collection – tył. *Fot. E. Wood.*

Fig. 31. Tailoring in A3 mail from The Wallace Collection – back. *Photo by E. Wood.*

Ryc. 31. Krój kolczugi A3 z The Wallace Collection – tył. *Fot. E. Wood.*

arch up. If one places the cap over the crown of the head with the expansions laid out in line with the nose and spine the cap sits perfectly. The mail falls neatly over the ears and down over the top of the neck, in fact forming what could be called "a mail sallet" (Fig. 39).

It can be seen that five of the shirts discussed here share numerous features that suggest a similar pattern of manufacture was used that could be adapted to suit the needs of the wearer. Expansions across the shoulders are countered by the same number of contractions on the back, normally formed into an incomplete 'V' shape. This draws in the mail around the waist and lower back, reducing the weight as well as providing a better fit. All of this mail has been suggested to be of German origin, and so it is possible that from the late 14th to mid 15th c. there was a set tailoring pattern used in German towns to make mail. This pattern was adapted to suit the measurements of the purchaser and his requirements for the garment. The shirt A1 demonstrates a method of tailoring that is different but achieves much the same result as the pattern used by A2, A3, RW1, RW 3 and the Hearst shirt.

How these shirts might relate to any pattern of mail construction used across elsewhere in Europe is

Fig. 32. Tailoring in A3 mail from The Wallace Collection – elbow. *Photo by E. Wood.*

Ryc. 32. Krój kolczugi A3 z The Wallace Collection – łokieć. *Fot. E. Wood.*

Fig. 33. Tailoring in RW1 mail from the private collection – back. *Photo by E. Wood.*

Ryc. 33. Krój kolczugi RW1 z kolekcji prywatnej – tył. *Fot. E. Wood.*

Fig. 35. Tailoring in A1 mail from the The Wallace Collection – underarm. *Photo by E. Wood.*

Ryc. 35. Krój kolczugi A1 z Wallace Collection – pacha. *Fot. E. Wood.*

Fig. 34. Tailoring in A1 mail from The Wallace Collection – back. *Photo by E. Wood.*

Ryc. 34. Krój kolczugi A1 z The Wallace Collection – tył. *Fot. E. Wood.*

Fig. 36. Tailoring in A1 mail from The Wallace Collection – underarm and hip. *Photo by E. Wood.*

Ryc. 36. Krój kolczugi A1 z The Wallace Collection – pacha i biodro. *Fot. E. Wood.*

Fig. 37. Tailoring in A7 mail from The Wallace Collection – front tailoring. *Photo by E. Wood.*

Ryc. 37. Krój kolczugi A7 z The Wallace Collection – rozszerzenia z przodu. *Fot. E. Wood.*

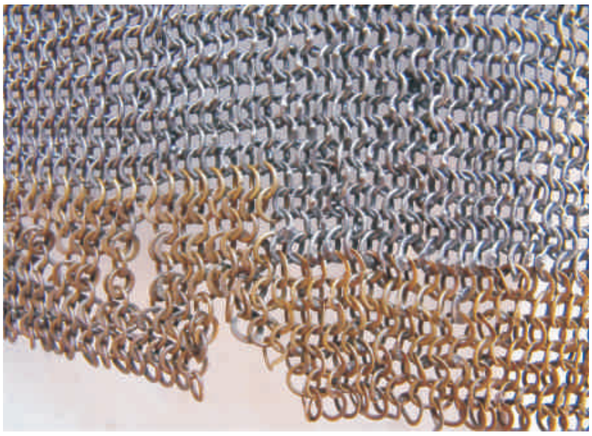

Fig. 38. Tailoring in A7 mail from The Wallace Collection – hem. *Photo by E. Wood.*

Ryc. 38. Krój kolczugi A7 z The Wallace Collection – krawędź. *Fot. E. Wood.*

as yet unclear. An extensive study of mail garments from across all of Europe is required in order to establish whether the pattern seen in three of these hauberks is specific to any particular region.

Metallography of the rings used in mail shirts

From the Wallace Collection:

A1 and A2. The rings examined from A1 and A2 were the same samples previously examined by

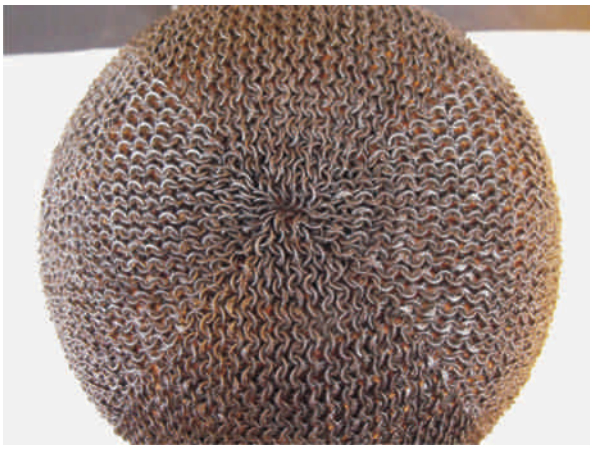

Fig. 39. A8 mail cap from The Wallace Collection – view from above. *Photo by E. Wood*

Ryc. 39. Kaptur kolczy A8 ze zbiorów The Wallace Collection – widok z góry. *Fot. E. Wood.*

D. Edge (2001) during conservation in 2001. These were re-polished and re-etched in order to confirm Edge's findings and also to perform microhardness tests upon them. Microhardness tests were performed using a Vickers Microhardness tester (100g load) and an average of ten reading taken.

A3 and A7. Single rings were taken from A3 and A7, these were set in polyester resin with the aim that they could be safely returned to the mail coats from which they were taken, after microscopic examination.

In addition, several rings from the rather composite mail shirt A6 were also examined. The results are discussed below.

From mail shirts loaned to the Wallace Collection by a private collector:

From the shirt RW1 – a latten (copper alloy) ring from the decorative edge about the bottom hemline. This had a rivet clearly made from iron.

Another (RW1 – ferrous) from the main body of the shirt. These were also embedded in polyester resin, for the same reason as the rings from A3 and A7.

A1 shirt

Indeed examination of samples from the shirt A1 shows that it was made from a heterogeneous iron (or rather, a low carbon steel) with a carbon content varying from 0-0.4% carbon (Fig. 40). There is a band of pearlite that runs through the ring, tailing off towards the rivet where significant deformation of the grains has taken place upon the setting of the rivet (Fig. 41, and detail Fig. 42).

Microhardness: the ring from A1 had a microhardness range of 195-329 VPH, which

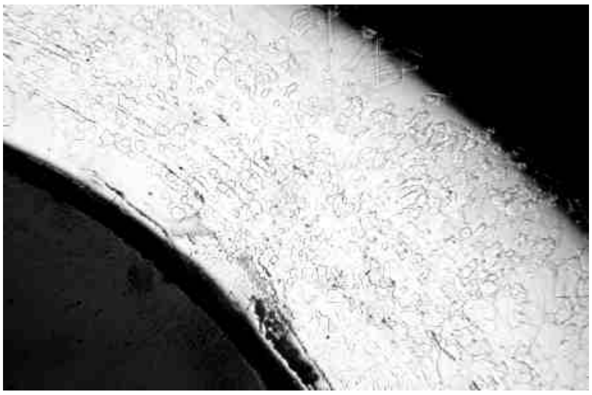

Fig. 40. Part of a link from shirt A1 (m2) in section (x 100). The white grains are ferrite (iron) and they are largely equiaxed. Evidently the wire has been annealed after drawing. The dark lines are slag inclusions elongated by the drawing of the wire. *Photo by A. Williams.*

Ryc. 40. Fragment ogniwa kolczugi A1 (m2) w przekroju (x 100). Białe ziarna to ferryt (żelazo) – i są one głównie równoosiowe. Z pewnością drut został po wyciągnięciu wyżarzony. Czarne linie to wtrącenia żużla, wydłużone wyciąganiem drutu. *Fot. A. Williams.*

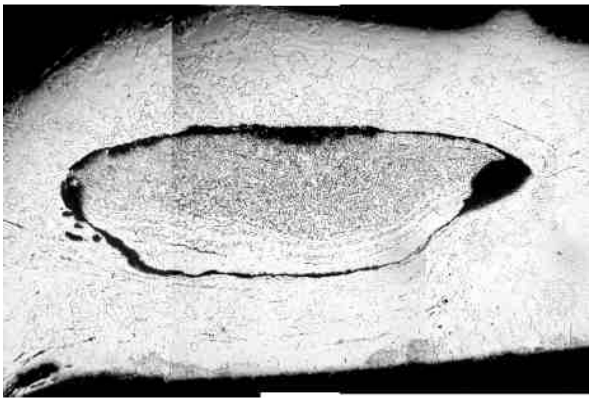

Fig. 41. Part of a link from shirt A1 (m combined) with rivet, shown in section. The ferrite grains are distorted in places. Evidently the rivet was driven in cold and was a tight fit in some places, and distorted the adjacent ferrite grains in the link. *Photo by A. Williams.*

Ryc. 41. Fragment ogniwa kolczugi A1 (m łączony) wraz z nitem w przekroju. Ziarna ferrytu zniekształcone. Ewidentnie nit został wbity w ogniwo na zimno i niezwykle ściśle, zniekształcając przylegające ziarna ferrytu w ogniwie. *Fot. A. Williams.*

is extremely high for a ferritic microstructure. One possible explanation is that there has been a considerable amount of cold working to close the ring.

A2 shirt

The ring from the shirt A2 is also made from a low carbon steel, produced from a heterogeneous billet but with a larger proportion of pearlite to ferrite suggesting an overall carbon content of around 0.4% (Fig. 43 and details Figs 44-45).

Microhardness of the ring from A2 (pearlite) ranged from 236 to 289 VPH (average = 263VPH),

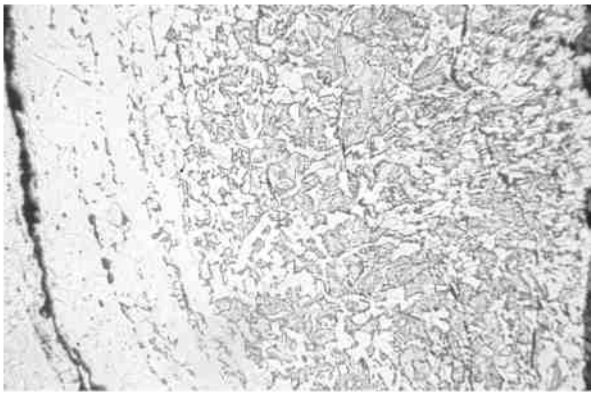

Fig. 42. Part of a link from shirt A1 with rivet (m 6), shown in section (x 200). The rivet is made up of a banded steel. The grey areas are pearlite. This is a microconstituent found in air cooled steels, containing both iron and iron carbide, and with a carbon content of approximately 0.8%. The rivet was made from a piece of steel which had been forged from a heterogeneous bloom, so that layers of ferrite alternate with layers of pearlite. The overall content might be around 0.6% C but there is no reason to suppose that this is anything but adventitious. Much medieval "iron" is in fact low-carbon steel. *Photo by A. Williams.*

Ryc. 42. Fragment ogniwa kolczugi A1 (m6) wraz z nitem w przekroju (x 200). Nit wykonano ze stali pasmowej. Szare obszary to perlit. Jest to mikroskładnik występujący w stali chłodzonej powietrzem, zawierający zarówno żelazo, jak i węgliki żelaza, ze średnią zawartością węgla na poziomie 0,8%. Nit wykonano z kawałka stali, wykutej z niejednorodnej łupki, w której warstwy ferrytu występują na przemian z warstwami perlitu. Całościowa zawartość węgla może sięgać 0,6 % C, ale nie ma powodu, żeby przypuszczać, że nie było to przypadkowe. Duże ilości średniowiecznego żelaza to w praktyce niskowęglowa stal. *Fot. A. Williams.*

while the rivet, consisting of ferrite, ranged from 189 to 283 VPH (average = 236VPH). The rivet had been extensively cold worked (in closing the ring) which increased its hardness at a cost of making it considerably more brittle.

A3 shirt

The microstructure was found to be mostly martensite with some ferrite and a small amount of pearlite in edges around the martensitic areas. This was made of a steel hardened by a delayed quench; a delay of only a few seconds between the removal from the heat and its submersion. This delay allowed some pearlite to form but the subsequent quench ensured that the rest of the steel formed martensite. There are many reasons that may have caused a delay in the quench, human error in the workshop, a distraction to the worker performing the job, even the mail not fitting right into the quenching container. It might even have been intentional if the mail maker wanted a shirt of less than maximum hardness (Fig. 46 and details Figs 47-48).

Microhardness ranged from 159 (ferritic areas) – 333 (martensitic areas) VPH.

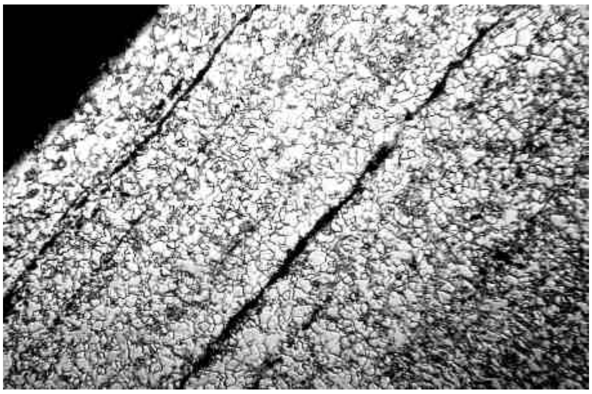

Fig. 43. Part of a link from shirt A2 (m2) in section (x 200). Ferrite and pearlite are visible. The overall content is perhaps 0.4% C. The dark lines are slag inclusions elongated by the drawing of the wire. *Photo by A. Williams.*

Ryc. 43. Fragment ogniwa kolczugi A2 (m2) w przekroju (x 200). Widoczny ferryt i perlit. Ogólna zawartość węgla na poziomie 0,4 %. Czarne linie to wtrącenia żużla, wydłużone wyciąganiem drutu. *Fot. A. Williams.*

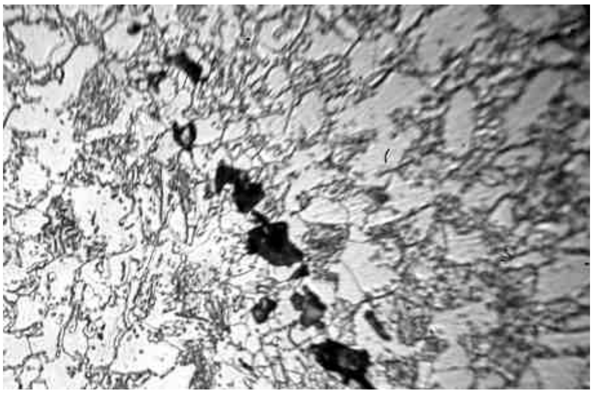

Fig. 45. An area of the link from A2 mail (m3) at higher magnification (x 800). The pearlite has partly broken down into globules of iron carbide. This is presumably the result of annealing the wire after drawing. *Photo by A. Williams.*

Ryc. 45. Powierzchnia ogniwa kolczugi A2 (m3) w znaczniejszym powiększeniu (x 800). Perlit częściowo rozpadł się w globulki węglika żelaza. Stało się tak prawdopodobnie wskutek wyżarzenia drutu po jego wyciągnięciu. *Fot. A. Williams.*

Fig. 44. An area around the rivet in the link from A2 mail (m1) (x 100). The rivet consists largely of iron. The grains in the link adjacent to the rivet show considerable distortion, cold to cold-working. *Photo by A. Williams.*

Ryc. 44. Obszar wokół nita w ogniwie kolczugi A2 (m1) (x 100). Nit zawiera głównie żelazo. Ziarna w przylegającym do nita ogniwie są znacząco zniekształcone, co spowodowane zostało obróbką kowalską na zimno. *Fot. A. Williams.*

A7 shirt

The microstructure of its ring is ferrite with a high slag content, typical of much medieval wrought iron (Fig. 49). The circumferential direction of the slag indicates a drawn wire, not a punched ring, as might have been expected. The metallurgy of A7 resembles that of A1 although it is made of much finer rings and therefore has a much denser weave. Whether this would have compensated for the low quality of the metal used is another question.

RW 1 shirt (samples of both ferrous and non-ferrous rings)

(RW1-latten) was a fairly heterogeneous copper alloy ring (Fig. 50). The microstructure was found to be a two phase alloy, evidently of a high zinc brass, the second phase being zinc rich beta phase (Fig. 51 at higher magnification).

XRF analysis perfomed on the ring suggested an 80:14:6 ratio of Copper: Zinc: trace elements (Iron, nickel and arsenic). These factors possibly demonstrate that the rings were produced from the recycling of heterogeneous scrap, which was also suggested by the presence of copper oxide inclusions located throughout the ring. The fact that the inclusions present in the ring are formed into long bands that run following the circumference of the ring indicates that the wire was drawn, as opposed to their having been cast into shape, or punched from a sheet.

The crystals of the alloy are all fairly equiaxed suggesting some annealing of the alloy had taken place. Cold working of copper alloys increases their hardness, at the expense of making them more brittle. This can be reversed by annealing the metal, reforming the crystals and removing dislocations that would lead to brittleness. The most likely occasion of this annealing in this ring would have been the heat treatment of the shirt after its construction.

Microhardness ranged from 112 to 143 VPH (average = 124 VPH), a reasonable hardness for a medieval copper alloy and comparable to iron and low carbon steel.

Another feature of note about this ring is the fact that it has an iron rivet, which is surprisingly common practice in latten rings. It is possible that the brass rings were the last to be fitted and as such

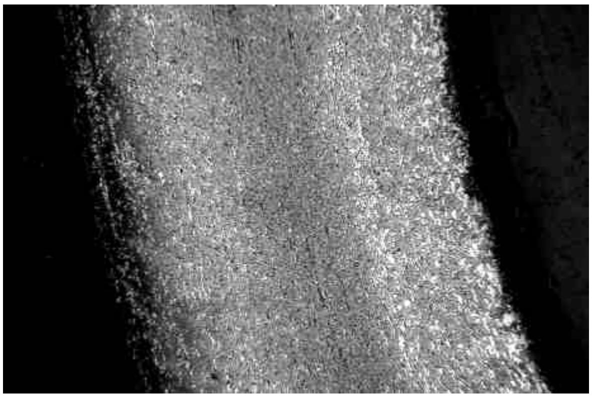

Fig. 46. Part of a link from shirt A3 (m1) in section (x 100). Ferrite and a dark-etching material (which is martensite) are visible. Quenching will not affect iron, and ferrite will appear unchanged, but steel is hardened by transforming into martensite. *Photo by A. Williams.*

Ryc. 46. Fragment ogniwa z kolczugi A3 (m1) w przekroju (x 100). Widoczny ferryt i trawiony na ciemno materiał (martenzyt). Hartowanie nie wpłynie na żelazo i struktura ferrytu pozostanie nie zmieniona, ale stal zostanie utwardzona poprzez zmianę w martenzyt. *Fot. A. Williams.*

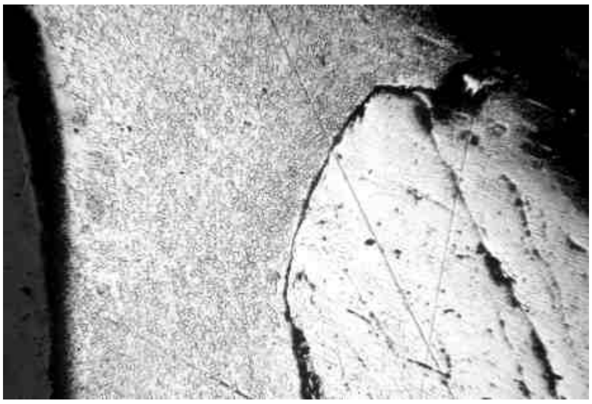

Fig. 47. An area around the rivet in the link from A3 (m2) (x 100). The rivet consists largely of iron, even though this would have been a weakness in the finished link. *Photo by A. Williams.*

Ryc. 47. Obszar wokół nita w ogniwie z kolczugi A3 (m2) (x 100). Nit zawiera głównie żelaza, mimo że stanowiłoby to słaby punkt w ukończonym ogniwie. *Fot. A. Williams.*

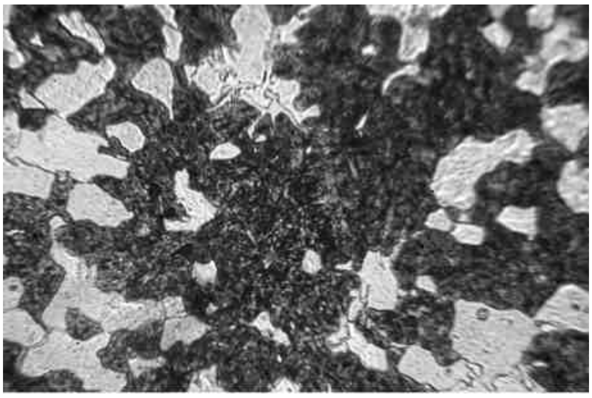

Fig. 48. An area around the rivet in the link from A3 (m6) – the dark-etching material at high magnification (x 800) is seen to be martensite mixed with granular carbides. This has been the result of a slack-quenching (a less than full quench, which would have formed an all-martensite microstructure). *Photo by A. Williams.*

Ryc. 48. Obszar wokół nita w ogniwie z kolczugi A3 (m6) – widoczny w dużym powiększeniu (x 800). Trawiony na ciemno materiał wydaje się martenzytem zmieszanym z ziarnistymi węglikami. Jest to prawdopodobnie wynik niepełnego hartowania (slackquenching) – polegającego na zanurzeniu przedmiotu w ośrodku chłodzącym i szybkim wyjęciu – pozostałe wewnątrz ciepło dokonuje odpuszczenia. Zabieg ten utworzył pełnomartenzytyczną mikrostrukturę. *Fot. A. Williams.*

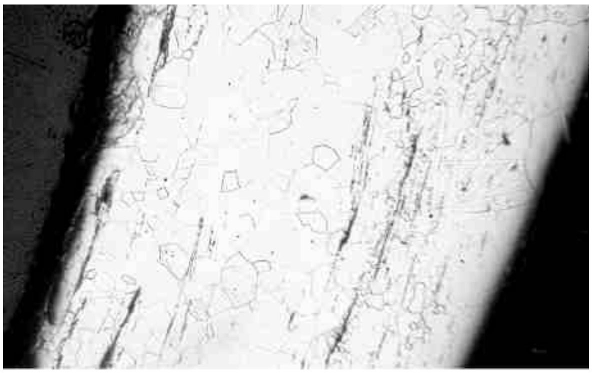

Fig. 49. Part of a link from shirt A7 in section (x 100). Ferrite and slag inclusions are visible. The rivet is very similar. *Photo by A. Williams.*

Ryc. 49. Fragment ogniwa kolczugi A7 w przekroju (x 100). Widoczne są ziarna ferrytu i wtrącenia żużla. Nit wykazuje bardzo podobną strukturę. *Fot. A. Williams.*

the mail maker simply used any leftover iron rivets available rather than make a new set of brass ones. The iron used in the rivet is of quite poor quality (Fig. 52), a large band of corrosion (doubtless accelerated by the galvanic effect of the copper) runs through the rivet, which is streaked with slag inclusions. This is typical of much bloomery iron. Such a poor quality iron would increase the chance of failure, for should the rivet break the ring would eventually twist free and open a breach in the mail.

Sample RW1 (ferrous) microstructure was found to be mostly tempered martensite (Fig. 53 and Fig. 54 at higher magnification) with some ferrite, but no pearlite, suggesting that the ring had been heat treated successfully by a full quench, followed by reheating to temper it. This contrasts with the microstructure of A3 where pearlite had been allowed to form suggesting that that shirt had been less effectively quenched. The slag content of the ring was relatively low, the ring being a good example of a bloomery steel. What slag is present, runs around the circumference suggesting that this ring was also made by drawing the wire and then riveting it shut.

Microhardness ranged from 388 to 476 VPH; average = 435 VPH. This would suggest a steel of carbon content around 0.5%, hardened by full-quenching and then tempering.

The rivet of this ring is of lower carbon content than the ring, because while the ring has formed

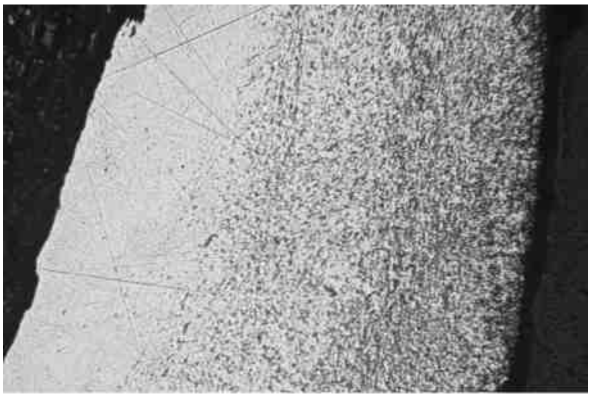

Fig. 50. Copper-alloy link from RW1 mail. *Photo by A. Williams.*

Ryc. 50. Ogniwo wykonane ze stopu miedzi z kolczugi RW1. *Fot. A. Williams.*

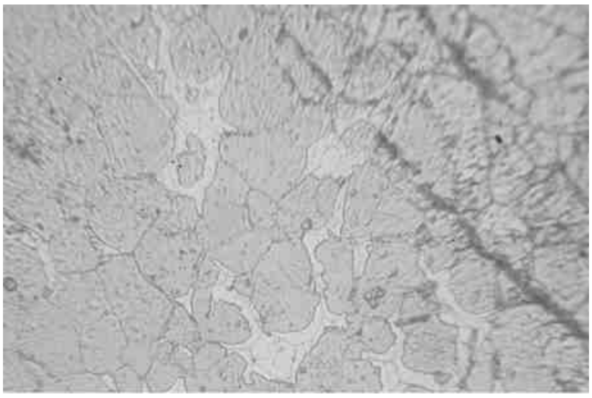

Fig. 51. Copper-alloy link from RW1 mail – detail at higher magnification (x 800). *Photo by A. Williams.*

Ryc. 51. Ogniwo wykonane ze stopu miedzi z kolczugi RW1 – detal w powiększeniu (x 800). *Fot. A. Williams.*

martensite the rivet remains ferritic in microstructure (iron being unaffected by quenching). There is however, a band of slightly higher carbon material running through the centre of the rivet indicating that it was made from a heterogenous bloom.

RW2 shirt

The microstructure was also found to be mostly tempered martensite, indicating a steel heat treated by quenching and tempering. Some ferrite was present but virtually no slag, and no pearlite (iron rivet – Fig. 55; steel ring – Fig. 56 and Fig. 57 at higher magnification).

Microhardness ranged from 360 to 380 VPH, which was slightly less hard than the ring from RW1, and which could be explained by the presence of some ferrite.

RW 3 shirt

The microstructure was yet again found to be mostly tempered martensite with very little slag (Fig. 58 and Fig. 59 at higher magnification).

Microhardness ranged from 383 to 452 VPH, similar to the sample from RW1.

The microstructure of the rivet was predominantly ferrite although it also had a martensitic band running through the middle, suggesting that it had been cut from a piece of streaky steel.

Such is the similarity of the steel, and its heat-treatment, used in this ring to that from the shirts of RW1 and RW2 it is tempting to argue for a common origin. If they did not all derive from the same workshop, then there were probably strong mutual influences.

Inventory number	Microconstituents	Microhardness of ring (VPH)	Rivet	Ring
A1	ferrite	262	Low C% steel work hardened	Low C% steel
A2	pearlite	263	Iron work hardened	Steel
A3	martensite + ferrite + pearlite	159-333	Iron	Partly hardened steel
RW1: “latten”	2 phase CuZn Alloy	124	Iron	Brass
RW1: ferrous	martensite + ferrite	435	Low C% steel	Hardened steel
RW2	martensite	360-380	Iron	Hardened steel
RW3	martensite	383-452	Low C% steel	Hardened steel
A7	ferrite		Iron	Iron

Table III. Summary of Results.

Tabl. III. Podsumowanie wyników badań.

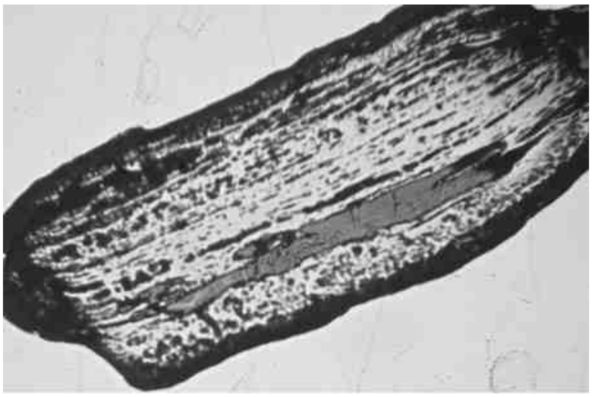

Fig. 52. An iron rivet in a copper ring from RW1 mail. *Photo by A. Williams.*

Ryc. 52. Żelazny nit w miedzianym ogniwie z kolczugi RW1. *Fot. A. Williams.*

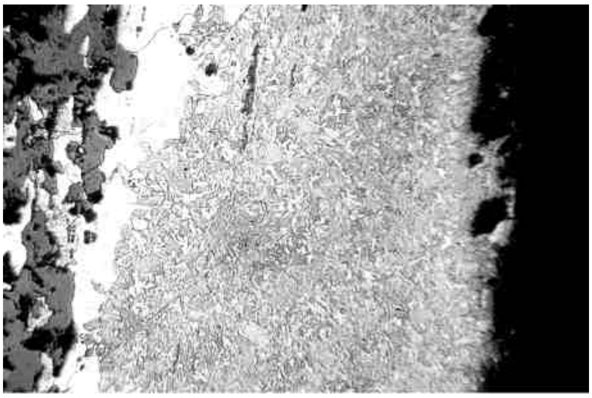

Fig. 53. Part of a link from shirt RW1 (m2) in section (x 100). A narrow band of ferrite is visible within an overall dark-etching material. *Photo by A. Williams.*

Ryc. 53. Fragment ogniwa z kolczugi RW1 (m2) w przekroju (x 100). Widoczne wąskie pasmo ferrytu na przeważającym tle trawionego na ciemno materiału. *Fot. A. Williams.*

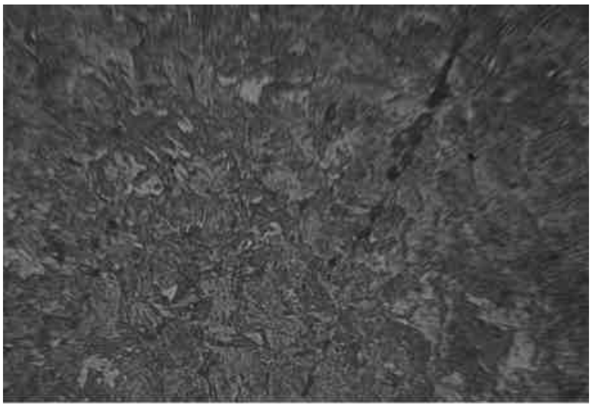

Fig. 54. Part of a link from shirt RW1 (m1). The dark etching material contains martensite and acicular carbides. Again, this has probably been the result of a slack-quenching operation. *Photo by A. Williams.*

Ryc. 54. Fragment ogniwa z kolczugi RW1 (m1). Trawiony na ciemno materiał zawiera martenzyt i iglaste węgliki. Jest to prawdopodobnie również wynik zastosowania niepełnego hartowana (slackquenching). *Fot. A. Williams.*

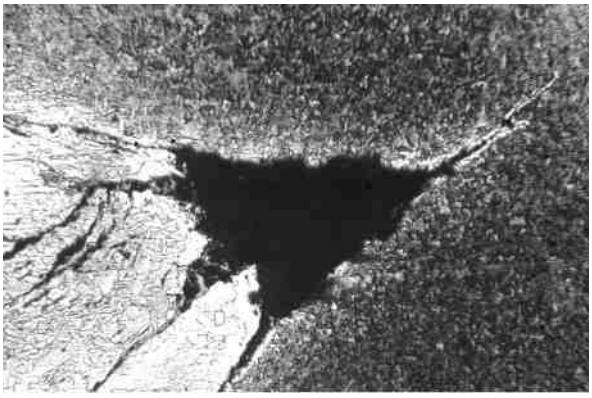

Fig. 55. An iron rivet in a hardened steel link from shirt RW2 (m1). *Photo by A. Williams.*

Ryc. 55. Żelazny nit w ogniwie z utwardzonej stali z kolczugi RW2 (m1). *Fot. A. Williams.*

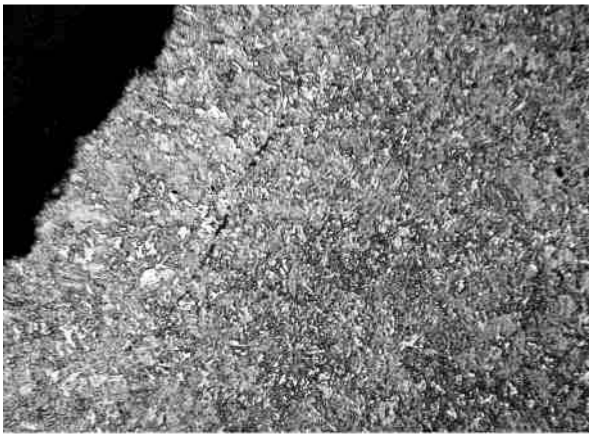

Fig. 56. Part of a link from shirt RW2 (m2) in section (x 100). The microstructure is a uniform dark-etching material (martensite). This is the result of a full-quenching operation. *Photo by A. Williams.*

Ryc. 56. Fragment ogniwa z kolczugi RW2 (m2) w przekroju (x 100). Mikrostruktura to jednorodny, trawiony na ciemno materiał (martenzyt). Jest on wynikiem pełnego hartowania zabytku *Fot. A. Williams.*

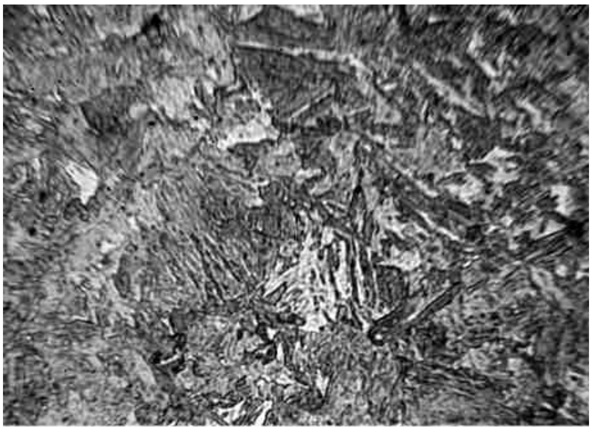

Fig. 57. Part of a link from shirt RW2 (m3) (x 800). The uniform dark-etching material is martensite, of characteristic lath-like appearance. *Photo by A. Williams.*

Ryc. 57. Fragment ogniwa z kolczugi RW2 (m3) (x 800). Jednorodny, trawiony na ciemno materiał to martenzyt w charakterystycznej listwowej formie. *Fot. A. Williams.*

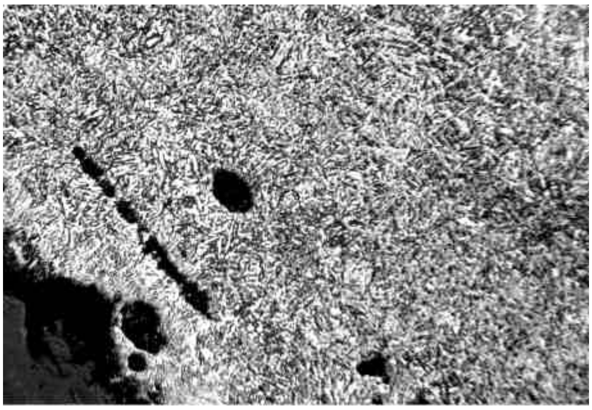

Fig. 58. Part of a link from shirt RW3 (m1) in section (x 100). The microstructure is a uniform dark-etching material (martensite). *Photo by A. Williams.*

Ryc. 58. Fragment ogniwa z kolczugi RW3 (m1) w przekroju (x 100). Mikrostruktura to jednorodny, trawiony na ciemno materiał (martenzyt). *Fot. A. Williams.*

Fig. 59. Part of a link from shirt RW3 (m2) (x 800). The uniform dark-etching material is martensite, probably tempered somewhat by reheating. *Photo by A. Williams.*

Ryc. 59. Fragment ogniwa z kolczugi RW3 (m2) (x 800). Jednorodny, trawiony na ciemno materiał to martenzyt, prawdopodobnie odpuszczony poprzez wygrzewanie. *Fot. A. Williams.*

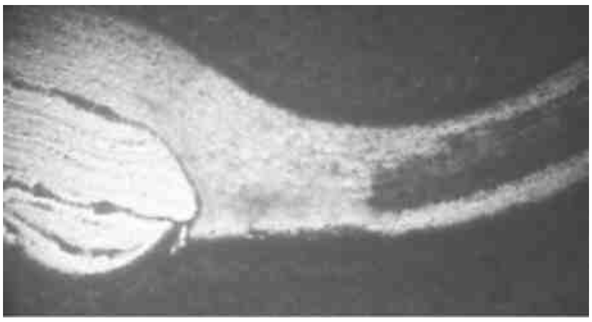

Fig. 60. A6 composite mail, ring 3 (body) – part of the ring next to the rivet. *Photo by A. Williams.*

Ryc. 60. Kompozytowa kolczuga A6, ogniwo nr 3 (korpus) – fragment ogniwa w pobliżu nitu. *Fot. A. Williams.*

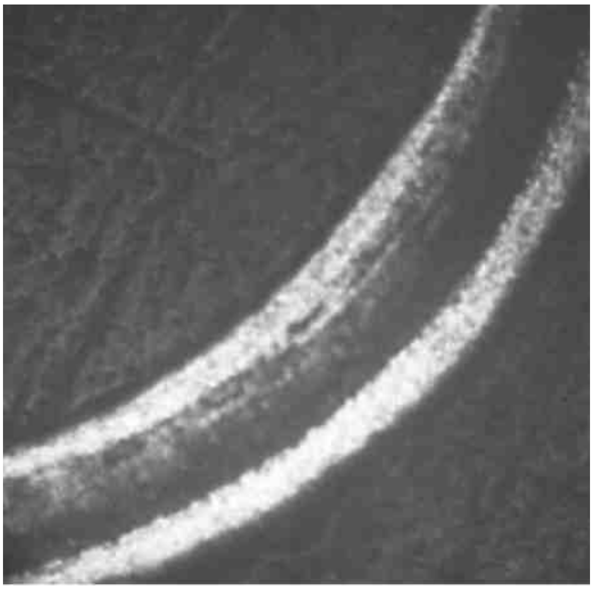

Fig. 61. A6 composite mail, ring 3 (body) – dark-etching martensite and bands of ferrite in the ring. *Photo by A. Williams.*

Ryc. 61. Kompozytowa kolczuga A6, ogniwo nr 3 (korpus) – trawiony na ciemno martenzyt i pasma ferrytu w ogniwie. *Fot. A. Williams.*

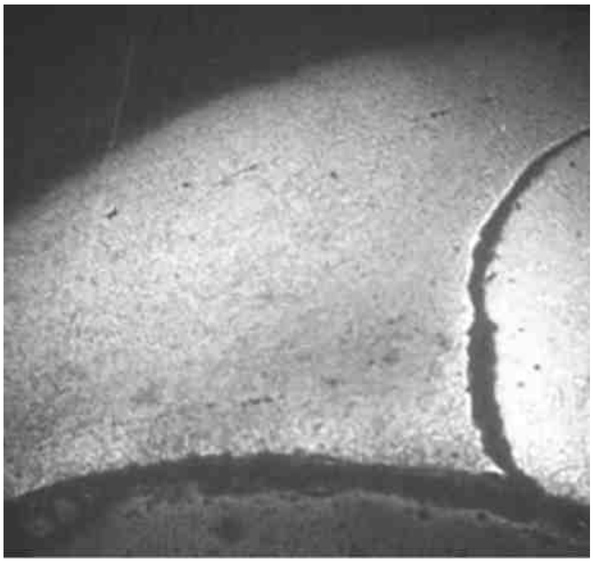

Fig. 62. A6 composite mail, ring 3 (body) – note the iron rivet in a hardened steel ring. *Photo by A. Williams.*

Ryc. 62. Kompozytowa kolczuga A6, ogniwo nr 3 (korpus) – zauważ występowanie żelaznego nita w utwardzonym, stalowym ogniwie. *Fot. A. Williams.*

Comments

Much mail was probably only made out of iron (Edge 2001, 229); however these shirts are evidently of higher quality. Four out of the seven mail shirts examined here were made of steel and hardened by heat treatment (Table III).

The fact that the ferrite grains around the rivet in the links from both the A1 and A2 shirts remain deformed by the riveting process indicates

Fig. 63. A6 mail, ring 2 (patch) – Dark-etching martensite and a band of ferrite in the ring. *Photo by A. Williams.*

Ryc. 63. Kolczuga A6, ogniwo nr 2 (łata) – trawiony na ciemno martenzyt i pasma ferrytu w ogniwie. *Fot. A. Williams.*

Fig. 64. A6 mail, ring 2 (patch) – ferrite and some banded pearlite. *Photo by A. Williams.*

Ryc. 64. Kolczuga A6, ogniwo nr 2 (łata) – ferryt i pasmowy perlit. *Fot. A. Williams.*

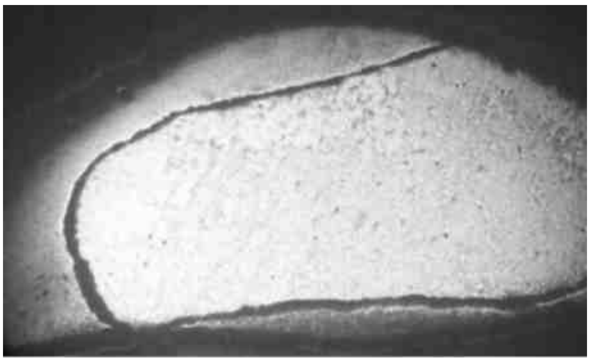

Fig. 65. A6 mail, ring 4 (mitten) – note the iron rivet in the steel ring. *Photo by A. Williams.*

Ryc. 65. Kolczuga A6, ogniwo nr 4 (mitynka) – odnotujmy obecność żelaznego nitu w stalowym ogniwie. *Fot. A. Williams.*

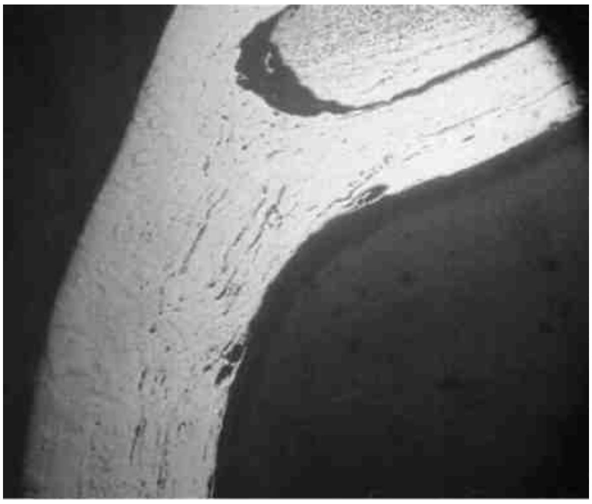

Fig. 66. A6 mail, ring 1 and rivet (seam) – ferrite and pearlite in the ring (part of the rivet is also visible). *Photo by A. Williams.*

Ryc. 66. Kolczuga A6, ogniwo nr 1 i nit (szew) – ferryt i perlit w ogniwie (widoczny również fragment nitu). *Fot. A. Williams.*

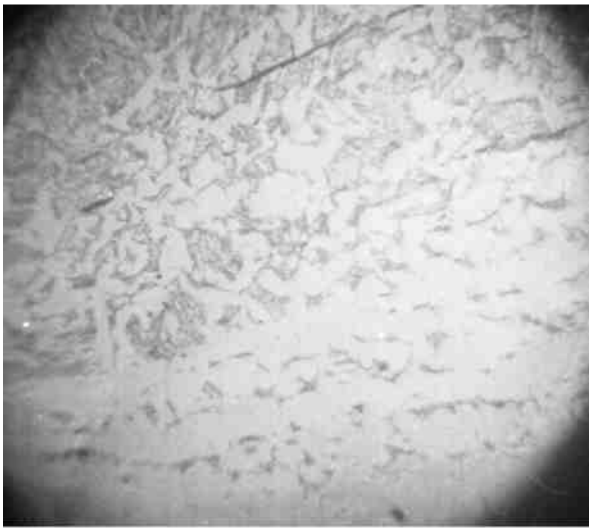

Fig. 67. A6 mail, ring 1, rivet at higher magnification (seam) – pearlite and slag inclusions elongated in the flat plane of the rivet. *Photo by A. Williams.*

Ryc. 67. Kolczuga A6, ogniwo nr 1, nit w dużym powiększeniu (szew) – perlit i wtrącenia żużla wydłużone w płaskiej płaszczyźnie nita. *Fot. A. Williams.*

that neither of those coats underwent any heat treatment after assembly, unlike the shirt RW1, where the ferrite grains around the rivet have been recrystallised, and now appear equiaxed.

Composite shirt A6

Wallace Collection A6 is a mail shirt that has often been neglected as it is hidden within the suit of plate armour A20, although these two items have no historical connection. It is dealt with here separately because any connection to the potential mail groups discussed above could not be established as it was impossible to examine it for ring counts and tailoring. The shirt is, however, still a very interesting piece, for other reasons. It has evidently been altered by the addition of mail patches down the front of the shirt and by attaching mail mittens to the sleeves. Indeed the sleeves themselves may well be later additions to the torso of mail. The different methods of attachment indicate that these alterations were not all carried out at the same time. The patches of mail were inserted into the mail shirt by using crudely made butted rings as were the mittens, while riveted rings were used to attach the sleeves.

During conservation work undertaken at the Wallace Collection some rings were removed for analysis, these were mounted and prepared for examination (Labelled A6, rings 1-4; Table IV). The results of this investigation proved to be helpful in establishing a relative chronology for the sequence of alterations to the shirt.

The body of the mail shirt (sample A6 ring 3) was made from steel wire, heat treated afterwards to harden it. The steel had formed martensite indicating that it had been quenched and tempered in order to increase its hardness and strength (Figs 60-62). Such heat-treatment is to be found regularly in armour, particularly that from the 15th and 16th c., when steel had become more common and the techniques for its heat treatment more widely practised (Williams 2003, *passim*). The mail patches (A6 ring 2) had also been heat treated to form martensite (Figs 63-64), as had the mittens (mail attached to cover the hands; A6 ring 4). The metal of sample A6 ring 4 was more homogenous in composition, so that its heat treatment was more successful than that of the others (Fig. 65).

So that although the mail shirt is a composite, four different areas from it were all made from medieval steels, hardened by heat treatment. The heterogeneous nature of the steels indicates that it was not 19th c. material that had been attached. The butted rings were however, made of round section wire, so these were probably 19th c. rings which were used to attach (or re-attach) spare patches of original mail to a damaged original shirt as a complete mail garment would have been more valuable to collectors.

A6 also contains seams joining the sleeves to the torso of mail rings made from riveted round wire (A6 ring 1) which is unlike the majority of the shirt, even the patches, which are riveted flat wire. A sample was taken from these rings to see if their position in the constructional sequence could be determined. The sample examined was made from iron (which is not hardened by heat treatment), but its rivet was made from a streaky steel (which had formed martensite) indicating that the ring had been inserted prior to the heat treatment of the whole mail shirt (Fig. 66-67).

A constructional sequence may therefore be proposed. Initially the mail garment that is now A6 was without arms and open at least in part at the front. At some later stage, perhaps in the 16th c., when round wire mail was more common, mail arms were added and the mail closed at the front to form a hauberk. It is probable that the shirt was heat treated at this stage to increase the hardness of the mail. In the 19th c. the mail had either become damaged, or been reopened at the front, so the patches of original mail were inserted (or re-inserted) using butted rings and the mail mittens were also attached (or re-attached) in the same way.

So that although this mail shirt is a composite it does seem to have been assembled in the 16th c. when the effective heat treatment of mail was regularly practised.

Sample No.	Location in shirt A6	Microconstituents	Microhardness Range (VPH)	Notes
A6 ring 1	Ring from seam joining sleeve to torso	ferrite ring with martensitic rivet	239-311	Round section wire. Probably 16th c.
A6 ring 2	Mail Patch at front	tempered martensite + ferrite	113-496	Flat section wire
A6 ring 3	Skirt of original shirt	tempered martensite + ferrite grains in parallel rows	483-713	Flat section wire. Not heated enough to fully homogenise the steel
A6 ring 4	Mitten	tempered martensite + ferrite	397-452	Flat section wire

Table IV. Summary of metallography results for A6.

Tabl. IV. Podsumowanie wyników badań metaloznawaczych pancerza kolczego A6.

A3 Front (mm)

R	1.93	2.09	1.986		1.99	1.87	1.83	L
	1.88	1.99	2.07	1.88	2.03	1.94	1.96	
1.83	1.87	1.78	1.90	1.89	1.87	1.87	1.88	1.79
1.84	1.74	1.73	1.78	1.75	1.76	1.71	1.79	1.67
1.68	1.73	1.61	1.63	1.65	1.74	1.76	1.71	1.68
1.66	1.69	1.53	1.55	1.67	1.57	1.55	1.54	1.64

A2 Front (mm)

R	2.18	1.99	2.23	1.99	1.98	1.90	L
	2.00	1.92	2.08	2.41	2.20	1.74	
	1.76	2.15	2.11	1.83	1.79	1.75	
1.79	1.75	2.14	1.88	2.01	1.98	1.90	1.83
1.90	1.65	1.79	1.91	1.92	1.98	1.93	1.90
1.87	1.82	1.82	1.75	2.06	1.84	1.88	1.81
1.82	1.78	1.82	1.94	1.92	1.85	1.87	1.83
1.78	1.75	1.70	1.69	1.86	1.76	1.71	1.74
1.54	1.57	1.69	1.58	1.65	1.66	1.71	1.64
1.66	1.68	1.60	1.65	1.58	1.66	1.62	1.64
1.59	1.65	1.58	1.52	1.61	1.68	1.58	1.64
1.60	1.65	1.49	1.54	1.62	1.62	1.50	1.69

- 1.30-1.39 mm
- 1.40-1.49 mm
- 1.50-1.59 mm
- 1.60-1.69 mm
- 1.70-1.79 mm
- 1.80-1.89 mm
- 1.90-1.99 mm
- 2.00-2.09 mm
- 2.10-2.19 mm
- 2.20-2.29 mm
- 2.30-2.39 mm
- 2.40-2.49 mm

RW2 Front (mm)

R	2.00	2.06				1.87	1.86	L
	1.79	1.90	1.89	1.91	1.89	2.02	1.86	
	1.92	1.87	2.02	1.80	1.95	1.90	1.93	
	1.76	1.87	1.76	1.98	1.80	1.88	1.77	
	1.80	1.72	1.79	1.83	1.78	1.96	1.81	
1.68	1.79	1.82	1.83	1.73	1.83	1.78	1.79	1.60
1.61	1.76	1.70	1.75	1.73	1.76	1.82	1.80	1.74
1.65	1.60	1.65	1.64	1.63	1.62	1.71	1.70	1.70
1.63	1.57	1.62	1.58	1.63	1.65	1.65	1.62	1.70
1.53	1.61	1.56	1.66	1.56	1.54	1.51	1.53	1.49
1.59	1.53	1.49	1.54	1.54	1.39	1.50	1.48	1.46
1.41	1.43	1.49	1.41	1.48	1.39	1.35	1.55	1.49
1.44	1.40	1.34	1.48	1.34	1.51	1.47	1.47	1.55
1.43	1.42	1.45	1.48	1.37	1.33	1.51	1.51	1.43

Chart 1. Wire thickness variations. Maps of the average wire thickness in the fronts of three mail shirts: A3 (measured in 10x20 squares), A2 and RW2 (measured in blocks of 10x10 squares). All clearly show how the mail is graded from top to bottom.

Zestawienie 1. Różnice w grubości drutu użytego do wyrobu kolczug. Ukazano średnią grubość drutu użytego na frontalnych częściach trzech kolczug: A3 (mierzonej w polach 10x20), A2 i RW2 (mierzonych w polach 10x10). Wyraźnie widać, że grubość drutu zmniejsza się od góry do dołu.

Acknowledgements

The authors would like to thank Richard Whittaker for his enthusiastic co-operation in the preparation of the exhibition in 2009 and in the work for this article. Conversations with Professor Erik Szameit (University of Vienna) have been particularly helpful, and we should mention the late A.V.B. Norman who initiated this project many years ago.

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PRZYCZYNEK DO KONSTRUKCJI I METALURGII PANCERZY KOLCZYCH EKSPONOWANYCH W THE WALLACE COLLECTION

Streszczenie

Na wystawie pancerzy kolczych, otwartej w The Wallace Collection w Londynie w 2009 r., pokazano zbiór obiektów pochodzących z tej kolekcji (nr A1, A2, A3, itd.), jak również ze zbiorów prywatnych (nr RW1, RW2, RW3).

W okresie późnego średniowiecza pancerze kolcze były nadal produkowane w szerokim zakresie, mimo że stanowiły one niedoskonałą ochronę przeciwko pociskom, co doprowadziło do prac nad różnymi wariantami zbroi wykonanej z metalowych płyt. Stosowane w tym czasie opachy, czyli elementy, które chroniły pachę rycerza w momencie zadawania ciosu, kształtem zbliżone były do prostokątów, wzmacnianych w centralnej części gęściejszym splotem pierścieni, dających tym samym jeszcze większą ochronę.

Większość spośród dobrze zachowanych do dnia dzisiejszego kolczug datowanych jest na XV i wczesny XVI w., mimo że w owym czasie pancerz ten nie był już głównym elementem uzbrojenia ochronnego. To właśnie z tego okresu pochodzi większość źródeł wykorzystanych w niniejszej pracy. Niektóre spośród tych kolczug posiadają pierścienie sygnowane nazwą miasta, w którym znajdował się warsztat bądź nawet imieniem wytwórcy. Jak dotychczas liczba ogniw używanych do wyrobu kolczugi nie została ściśle udokumentowana, aczkolwiek obliczenia wahają się pomiędzy 15 a ponad 40 tys. Stąd też założeniem niniejszej pracy było uściślenie liczby wykorzystanych w 12 kolczugach pierścieni. Kolczuga sięgająca pasa („hauberk") z długimi lub krótkimi rękawami składająca się z pierścieni o średnicy wewnętrznej ok. 7 mm liczy średnio ok. 28 685 ogniw. Kolczuga zrobiona z pierścieni o mniejszej średnicy wewnętrznej wynoszącej ok. 5-6 mm ma odpowiednio większą ilość pierścieni. Tego typu koszula nr A7 wykonana została z niemal 150 000 ogniw. Wydaje się, że górne partie kolczugi wyrabiano z drutu nieco grubszego niż ten, który był używany do dolnych partii. Zagadnienie to zostało objęte dogłębniejszymi badaniami. Zróżnicowanie średniej grubości pierścieni poszczególnych partii kolczugi został przedstawione na uproszczonym schemacie kolczugi, tak aby umożliwić wyjaśnienie tego zagadnienia – czy taki układ pierścieni był zamierzony czy jedynie przypadkowy. Na trzech kolczugach (A2, A3 i RW2) zostało zaobserwowane występowanie pierścieni wykonanych z grubszego drutu w górnej części kolczugi natomiast cieńszego w dolnej. Terminem „dopasowanie" określa się zmiany występujące w splotach pierścieni dokonywane za pośrednictwem dodawania dodatkowych bądź odejmowania poszczególnych ogniw. Termin „poszerzenie" dotyczy zmian wertykalnych wynikających z dodania kolejnego pierścienia do normalnego wzoru 4 x 1. Pierścień ten jest następnie wykorzystywany w splocie niższego rzędu w celu jego poszerzenia. Termin „zwężenie" jest w zasadzie odwrotnością przedstawionej wyżej sytuacji. Usunięcie jednego ogniwa z szerokości splotu powoduje, że trzy pierścienie z górnego rzędu są zaplatane w jeden z dolnego. Szczegółowo został omówiony krój sześciu kolczug. Wszystkie kolczugi należą do wariantu kolczug w całości nitowanych. Wszystkie poszczególne pierścienie są łączone przy pomocy niewielkich nitów, które we wszystkich przypadkach posiadają kształt klina.

Konstrukcja rękawów kolczugi, tak by pasowały one do budowy ciała, jest dużo bardziej złożona niż wyrób prostej cylindrycznej formy, gdyż każdy dodatkowy pierścień na ramieniu może powodować niedogodności. Kolczuga musiała być zwężana dzięki odejmowaniu pierścieni z poszczególnych rzędów poczynając od pachy, a kończąc na ramieniu. Łączenie na łokciu wprowadzono, by udogodnić zgięcie ręki. Charakteryzuje się ono znaczną ilością poszerzeń biegnących od części wewnętrznej ręki, zbiegających się na łokciu i tworzących rodzaj kolczego „worka", luźno zwisającego w momencie kiedy ramię jest wyprostowane, natomiast ciasno naciągniętego, kiedy łokieć jest zgięty. Od łokcia, wzdłuż całego przedramienia, rękaw nadal jest zwężany. Nadgarstki posiadają rozszerzenia skonstruowane tak, aby obejmowały dolną część dłoni. Można je odnaleźć w kolczudze RW1, nie posiada ich natomiast kolczuga A3.

Omówione zostały również badania metalograficzne pierścieni użytych w analizowanych kolczugach. Większość kolczug prawdopodobnie została wykonana z żelaznych ogniw – jednak bez względu na to, są one ewidentnie pancerzami wyższej klasy. Cztery spośród siedmiu badanych tu kolczug wykonane zostały ze stali zahartowanej poprzez obróbkę cieplną. Fakt, że ziarna ferrytu wokół nitu w łączeniach obu kolczug A1 i A2 pozostają nie zdeformowane w wyniku procesu nitowania wskazuje, że żadna z tych kolczug nie została poddana obróbce cieplej już po zmontowaniu. Zupełnie inaczej niż w kolczudze RW1, gdzie ziarna ferrytu wokół nitu zostały poddane rekrystalizacji i obecnie występują jako równoosiowe. Dodatkowo badaniom metalograficznym poddano kilkanaście ogniw z okazu nr A6, wykonanego z nitowanych i zgrzewanych pierścieni, który został wyprodukowany w XVI w., kiedy to właściwa obróbka cieplna kolczug była powszechnie praktykowana.

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