TECHNOLOGY
AND
CULTURE

1960

Methods of Making Chain Mail (14th to 18th Centuries) A Metallographic Note

CYRIL STANLEY SMITH*

METALLOGRAPHY PROVIDES a useful adjunct to historical or archaeological studies. A great deal can be learned from the microstructure of a metallic object about the techniques used in making and treating it. An example is provided by the use of such a method on links of chain mail armor, the manufacture of which has been discussed by Burges[1] and Burgess.[2] Both authors believe that riveted links were made by coiling drawn wire round an appropriate mandrel, cutting to give a series of rings, then overlapping and flattening (perhaps in a die) to give a thickened section through which a rivet hole is drifted with a pointed tool, the rivet being inserted and upset by the use of pliers at the time of assembly of mail. Burgess describes an ingenious set of simple tools which he had devised for the sequence of operations, although he provides no evidence beyond plausibility that they were actually used by makers of mail in earlier times. Some mail is composed entirely of riveted links, but a more usual form is alternate rows of solid and riveted ones. Burges believed that solid links were made by punching from sheet iron with a double punch or by punching a single hole and trimming the outside.

Through the courtesy of Mr. S. V. Granscay, Curator of Arms and Armor at the Metropolitan Museum of Art in New York, I was able to examine some sixteen links from various suits of armor of known provenance. After superficial examination, the links were sectioned, mounted, polished, and etched following standard metallographic procedures. This permitted the distribution of slag

* Professor of Metallurgy and one time Director of the Institute for the Study of Metals at the University of Chicago, Dr. Smith has done outstanding research in the structure and physical properties of metals. He has also edited and annotated English translations of some important metallurgical classics.

inclusions to be seen, as well as local variations of carbon content and heat treatment. The microhardness was also measured. Table 1 describes the links studied and summarizes the findings.

Most of the links are made of soft wrought iron, often containing large amounts of slag. Only three (Nos. 4, 6, and 16, Figs. 5 and 6) contain enough carbon to be classified as steel, and these alone had been given a heat treatment to harden them. Samples of these were heat treated in my laboratory to give a normalized structure; the microscope then showed that there was a slight gradient in carbon content, decreasing toward the outside of the wire. The links had therefore not been case hardened after they had been shaped, but rather had been made of an initially uniform steel wire which had lost some carbon during the working process. The decarburized areas around rivet holes and other points(appearing white in Figs. 5 and 6) confirm this.[3]

A number of links contain small amounts of spheroidized iron carbide, indicating that the material had been worked and/or annealed at a temperature below the transformation point but sufficiently high to cause recrystsllization and softening of the work hardened material—perhaps about 700°C. Most of the links show a structure of relatively uniform equiaxed ferrite grains indicating that the rings had been heated after final shaping. A few of them show signs of cold deformation (probably from unintentional bending or battering), but not one had been left in the cold drawn or rolled condition: all had been annealed after the wire had been made. Two of the Turkish links (Nos. 10 [Fig. 8] and 11) showed some cold deformation which had clearly occurred during the final stamping of the surface inscription, while the third (No. 15) seems to have been hot stamped.

All of the links were made from wire, bent to a circular form and closed by either riveting or welding. The welded links were somewhat less regular in shape than the others, usually flattish in section and often composed of two or three complete turns welded together instead of only a small overlap weld. None of the links had been made by punching or cutting circles of sheet as suggested by Burges,[4] for the streaks of slag or carbon segregation always run circumferentially (Fig. 3). This is hardly surprising, for the manufacture of suitably matched punches and dies would call for a precision of workmanship beyond that of the armorer.

TABLE 1

Ref. No.	MMA Description and No.	Microhardness *	Approx. carbon Content **	Remarks
1.	Brayette, German, *ca*. 1525. Riveted Links of flat wire; solid, half round. 27.183.14.	155 (143-162)	0.0	Drawn (?) wire, annealed. Round rivet, not headed either end.
2.	Shirt of Mail, German, *ca*. 1500. Solid link, half round wire; riveted Link, flat. 29.150.9 v. See Fig. 4.	R 178 (171-180; [238 hard spot]) S 154 (130-220)	 0.0	Slit wire, only slightly drawn, annealed. Rectangular rivet, not tapered.
3.	Shirt of Mail, German, *ca.* 1500. Riveted link, flat wire; solid, half Round. 14.25.2568. See Fig. 2.	R 135 (121-150) S 174 (152-184)	0.0	Same as No. 2.
4.	Shirt of Mail, German, *ca*. 1525. Riveted link, flat wire; solid, half round. 14.25.1555. See Figs. 1, 3, 5, and 12.	R 330 (274-346; [soft areas 147-206]) S 195 (162-265) Four other riveted links had average hardnesses 462, 461, 446, and 416 respectively in the hard zones with soft spots 168 to 294.	0.5	Drawn wire, ends folded and welded to give thickened part for rivet. Quenched (not above *ca.* 850°C.) and tempered.

5.	Shirt of Mail, German, *ca*. 1525. All riveted links (flat wire). 54.46.2.	176 (167-182)	0.2?	Perhaps slightly drawn after slitting. Annealed. Curious structure with both pearlite and spheroidized carbide.
6.	Shirt of Mail, German, *ca*. 1550. All riveted links (flat wire). 25.188.9. See Fig. 6.	465 (393-530)	0.6	Drawn wire. High carbon content, hardened by quenching and tempering.
7.	Shirt, German, *ca*. 1575. All riveted links (round wire). 29.158.176. See Fig. 13.	198 (184-234)	0.0	Drawn wire, possibly riveted hot but both links and rivet body show some grain distortion.
8.	Shirt, German, *ca*. 1575. All riveted links (round wire). 27.237.	153 (137-177)	0.0	Drawn wire. Annealed.
9	Cape, German, *ca*. 1575. All riveted links (round wire). 14.25.1539.	179 (132-222)	0.0	Drawn wire. Very dirty metal. Annealed.
10.	Shirt, Turkish, 17th cent. Solid and double riveted links (both flat wire). 36.25.33. See Figs. 7 and 8.	R 148 (137-183) S 196 (181-216)	0-0.15	Poor quality wire, cut from strip or assembled by welding many small pieces. Design cold stamped on to surface of welded link.
11.	Shirt, Turkish, 17th cent. Solid and riveted links (moulded section). 14.99.28.	R 138 (129-147) S 224 (207-241)	0.05 0.0	Wire slightly drawn to shape from cut strip. Annealed. Rivet driven cold.

12.	Shirt, Persian, 18th cent. Solid and riveted links (round wire). 14.25.1562. See Figs. 9 and 14.	S 239 (213-258) R 148 (139-178)	0.0 0.05	Drawn wire. Rivet made of cold drawn wire, not annealed.
13.	Shirt, Persian, 18th cent. All riveted links (round). 36.25.476. See Fig. 10	125 (91-180)	0.01	Drawn wire, containing many slag inclusions. Annealed.
14.	(Walker's Art Gallery) Coif, European, 14th cent. Round wire, riveted. See Fig. 11.	156 (139-176) 168 (144-202) (2 sections in the same link)	0.05	Drawn wire, badly corroded. Deformed metal around rivet shows partial recrystallization, but rivet has distorted structure and was perhaps driven at low red heat.
15.	Shirt, Turkish, 15th cent. Riveted and solid links, flat. 36.25.489 E.	152 (125-194)	0.0	Probably slit wire, raised design struck in heated metal. Many links poorly welded.
16.	Shirt, European, 16th cent. All riveted links. 29.158.3 F.	Four separate Links: 243 (226-257) 302 (281-341) 216 (165-337) 168 (143-199)	0.4?	Drawn wire, heat treated to harden. The softest of the four links examined was carbon free, perhaps introduced in a later repair.

*Vickers indenter, 200 gram load. First no. is average hardness from six or more individual impressions, while the numbers in parentheses represent their range. R = riveted links, S = solid links.
**Estimated from structure.

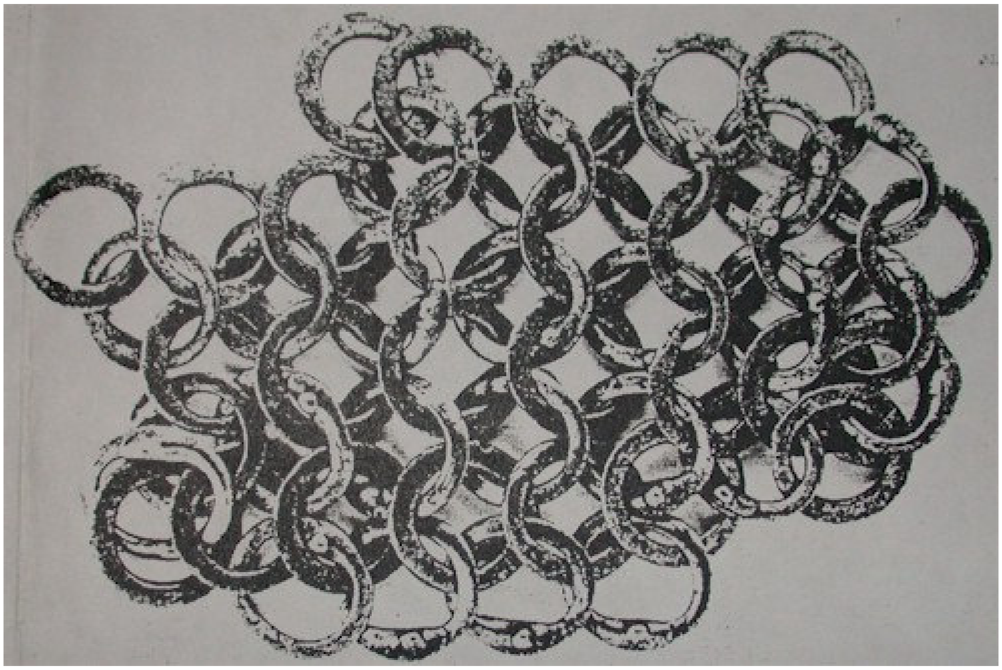


Fig. 1. Portion of assembled mail shirt. (Specimen No. 4, German, *ca*. 1525) x 1.5.

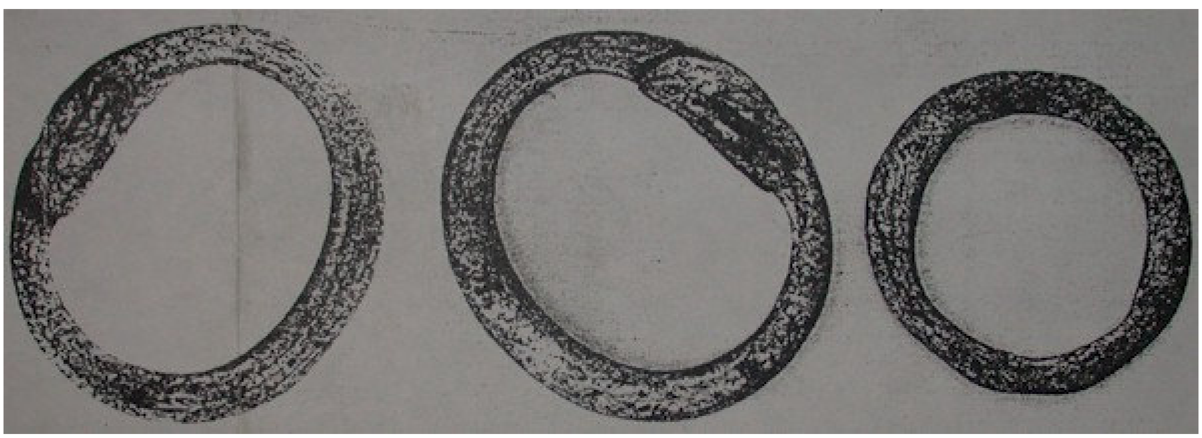


Fig. 2. Two links from shirt No. 3 (German, *ca*. 1500). Both sides of the riveted link are shown. X 5 *(photo reduced 25%).*

Fig. 3. Plane section beneath surface of welded link from sample No. 4. Etched. x 5.

Figs. 4-11. Photomicrographs of cross sections of various links, after etching with 2 percent nitric acid in alcohol to develop the structure.

Fig. 4. No. 2-R, x 50 (*photo reduced 30%*)

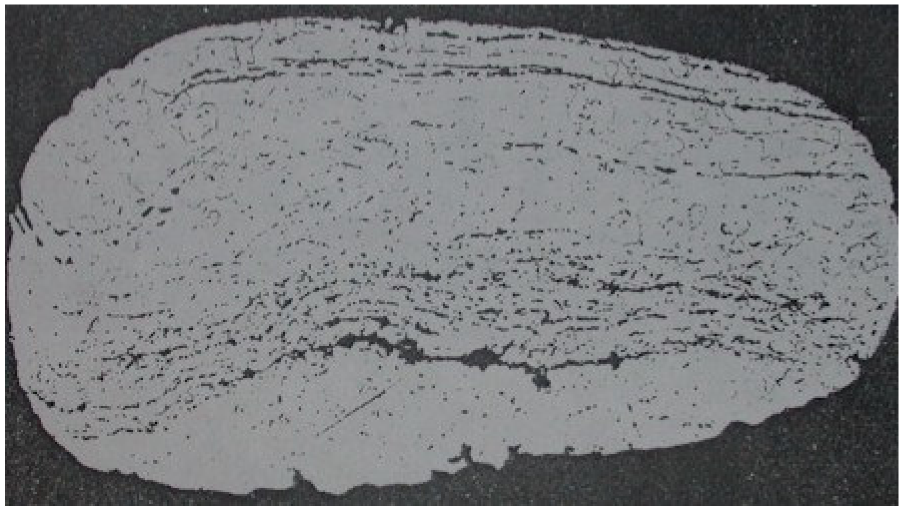


Fig. 5. No. 4-R, x 60 (*photo reduced 30%*). Section near rivet. The structure opposite the rivet was like that of Figure 6.

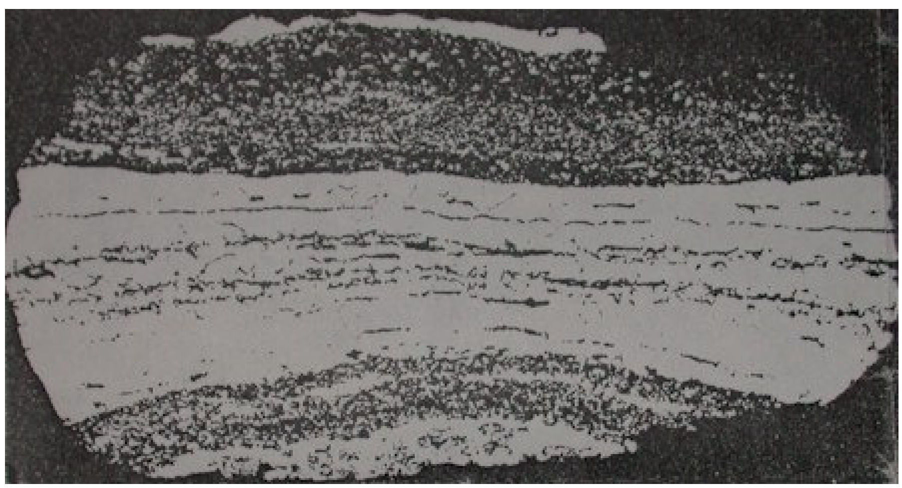
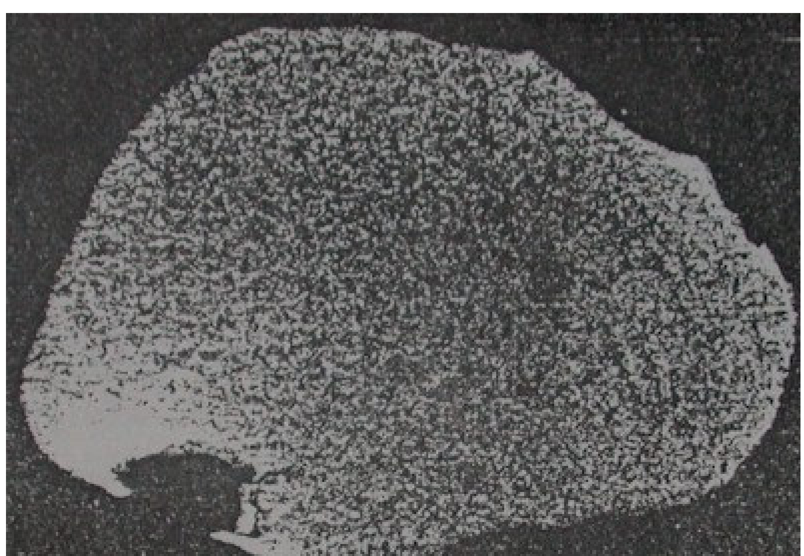


Fig. 6. No. 6-R x 75 (*photo reduced 20%*)



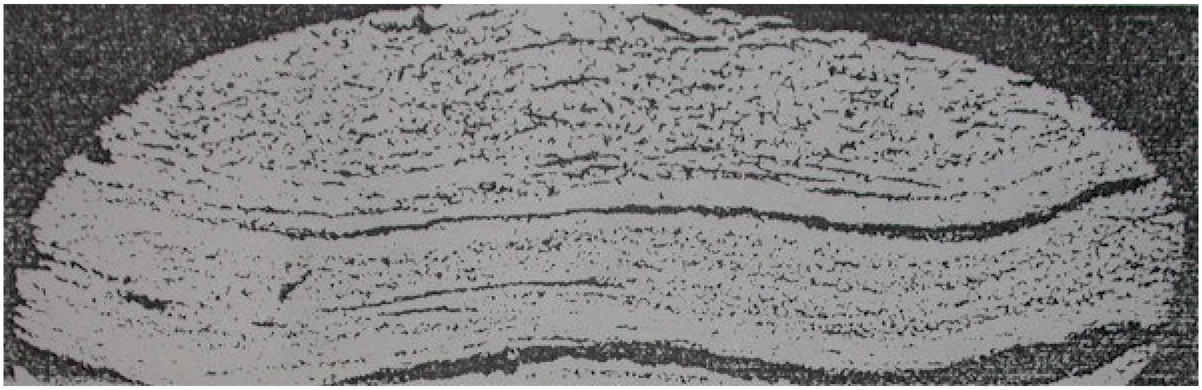


Fig. 7. No. 10-R, x60 (*photo reduced 35%*)

Fig. 8. No. 10-S, x 60 (*photo reduced 5%*)

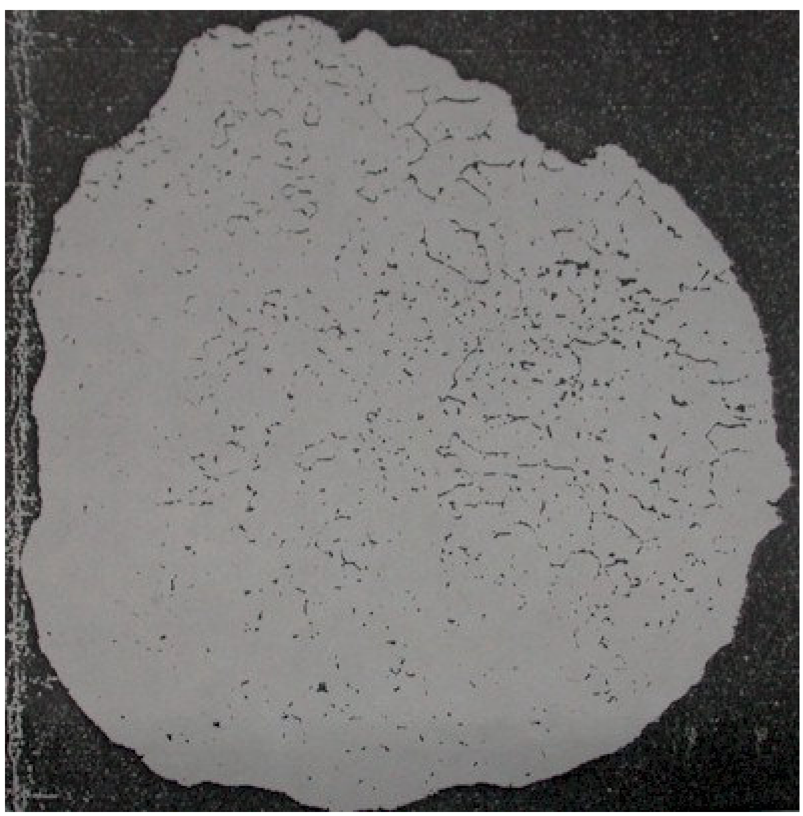


Fig. 9. No. 12-R, x 75 (*photo reduced 35%*)

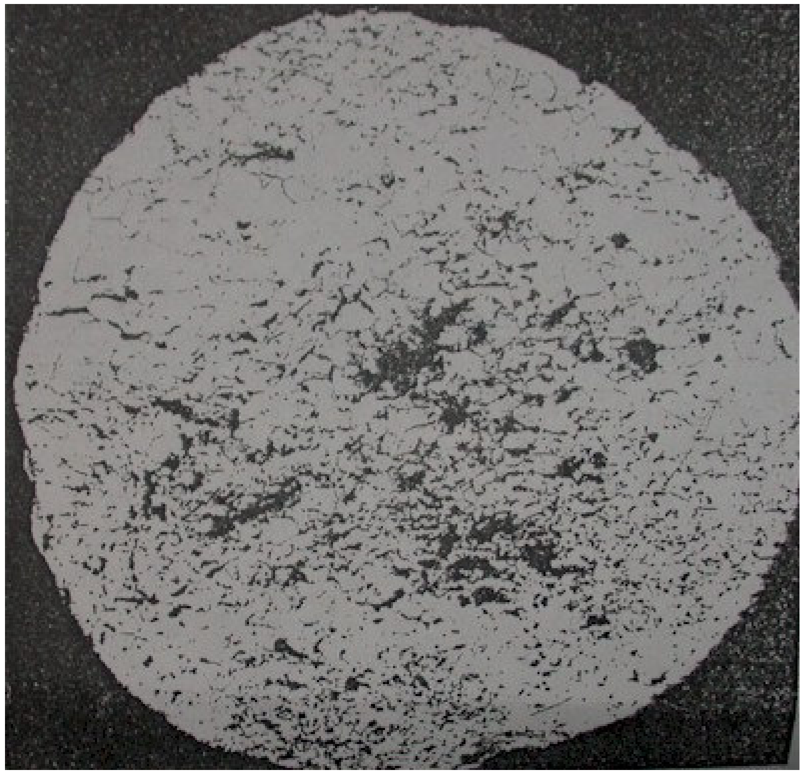
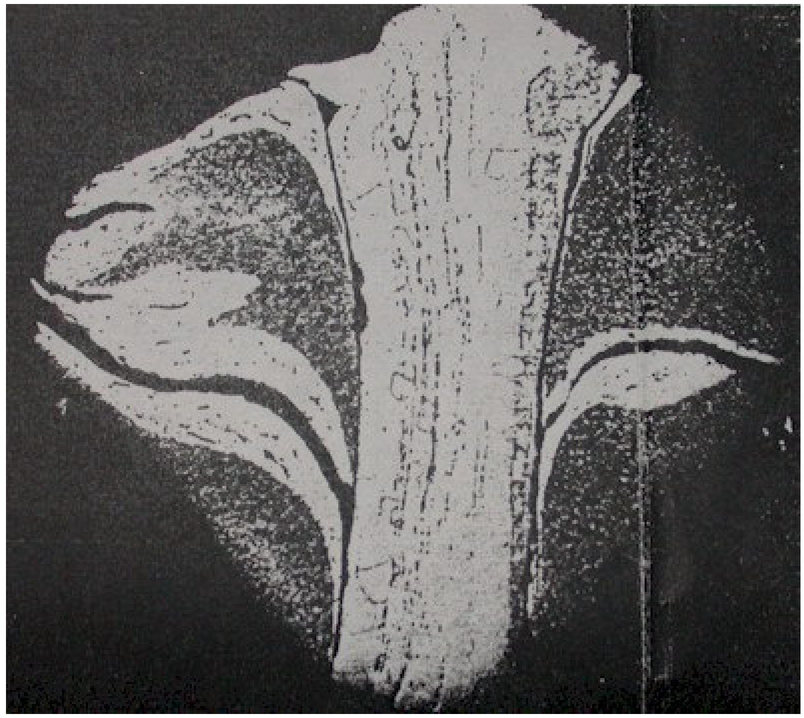


Fig. 10. No. 13, x 75 (*photo reduced 35%*)

Fig. 11. No. 14, x 75 (*photo reduced 5%*)

Fig. 12. Cross section through riveted joint in link of shirt No. 4, showing surface decarburisation and distortion of metal due to drifting the hole and driving the rivet. Etched. x 50 (*photo reduced 35%*)



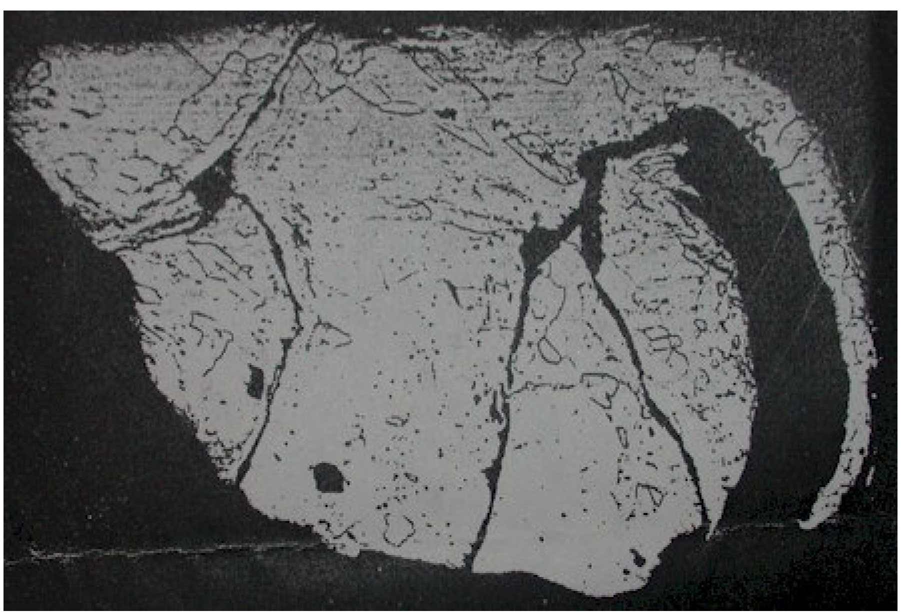


Fig. 13. Cross section through rivet in No. 7. Etched. x 50 (*photo reduced 10%*)

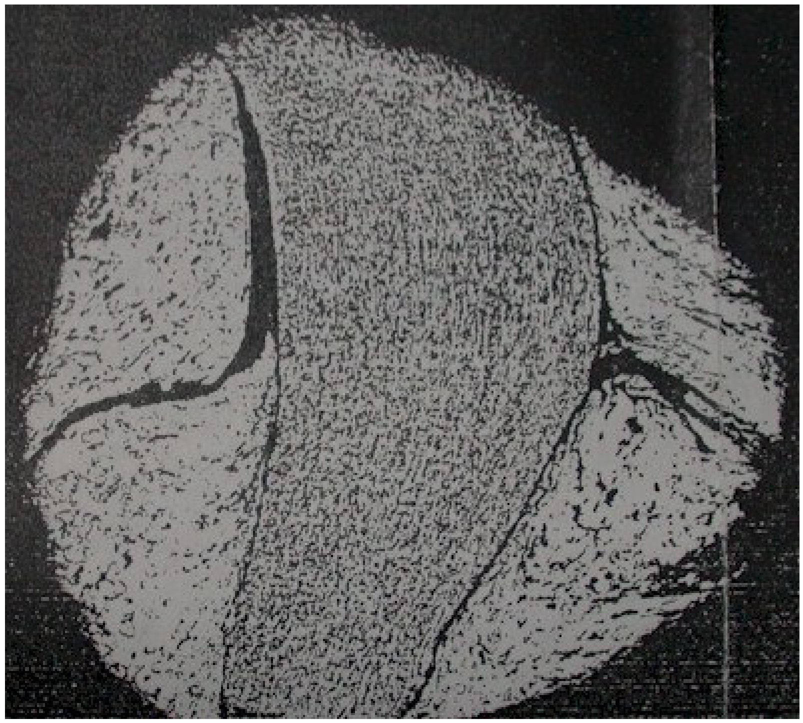


Fig. 14. Cross section through rivet in shirt No. 12. x 50 (*photo reduced 35%*). Note the heavily elongated grains in the cold-drawn rivet wire.

The welded links were not finished by forging to their final section but had been partly filed or otherwise cut, as can be judged from the intersection of the present surface with the fibre of the metal. Despite the amount of hand work involved in welding it, it was evidently comparable in cost with riveting, otherwise welded links would not have been used so frequently. They would add little to either the strength or the beauty of a suit in which half the links had to be closed by riveting during assembly.

The cross sections of the links normal to the wire axis give some information on the manner of making the wire. Nos. 8, 12, 13, and 14 (Figs. 9, 10, and 11) have a rather uniform distribution of slag and carbide particles such as would result from drawing a wire from a forged rod, maintaining a circular cross section throughout. The Turkish links Nos. 10 (Figs. 7 and 8) and 11 have slag stringers running nearly parallel to each other right across the wire section, and show unmistakably that the wires had been cut from a thin plate or strip and filed, scraped or abraded to the present shape: they are definitely *not* made of drawn wire. Even on of the German links (No. 2, Fig. 4) shows very little deformation of a lamellar structure and had probably been only lightly hammered to shape from a slit strip. The other links have an intermediate structure, such as would result if a strip had been cut from a sheet at a larger size (e.g., about 3 to 5 mm. square) and then drawn down to the final section through a relatively small number of dies. This is indeed a logical and likely method of making small-diameter wire from iron and steel in the days before it became possible to hot roll rod in sections small enough for wire drawing.

The rivets are all made of carbon-free iron, even in the hardened steel links. Most of the rivets are of rectangular section and profile, not tapered in either direction, as if they had been cut from strip. The riveting is generally poorly done, and very few of the rivets pass completely through the two pieces to form a good head on both sides: the bulge on the under side is usually composed more of distorted ring than of rivet. Although this would maintain a desirable smoothness on the inside of the mail and would not need a two-stage fitting operation, it would be mechanically weak. In No. 4, the enlarged portion of the ring through which the rivet passed was apparently made by folding back a short length of wire and welding it to itself and flattening. This was deduced from the local presence of layers of slag and metal of different carbon contents (Fig. 5) which are not present in the wire opposite the joint. One of the Turkish links (No. 15), which bears a heavily stamped design, actually has fake rivet heads. Many of the rings in this shirt are not welded, although overlapping wires are flattened—perhaps just an unintentional result of careless welding at too low a temperature. Some of these links have small copper rivets, apparently added later. The rivet heads on most of the samples are spread out very flatly, suggesting closure with a sharp hammer blow instead of slow pressure, which would cause deep deformation. In one sample (No. 12, Fig. 14) the rivet itself was made of heavily cold-drawn wire. The deformation of the slag streaks in the links in the vicinity of the rivet holes in all the links that were examined shows without a doubt that the holes were drifted with a tapered punch, not drilled. The drifting, however, was done hot (or the links were subsequently annealed) for the metal has recrystallized and the grains themselves show little if any deformation. Nos. 3, 4, and 6 show no residual distortion of the grains in the deformed head of the rivet, which therefore must have been driven hot or subsequently annealed. Conversely, however, the contacting surfaces of the rivet and link in most of the others show signs of local deformation which supposedly occurred during the driving of the rivet when cold.

The Turkish links have a design in relief. That this was stamped with a coining die, and not carved or etched, is deduced from the fact that the slag streaks and grains in underlying metal follow the contours of the surface (Fig. 8); moreover, the design is generally more truly circular that the rings themselves.

These findings are in general consistent with the sequence of operations described by Burgess,[5] although they do not prove that the tools he suggests were used. The fact that the wire from which some of the links, both Oriental and European, had been made was not drawn through dies upsets the contention made by Burgess (and by others) that “it is likely that the presence of mail in any civilization proves that the knowledge of wire-drawing was in existence at that time.” Though drawing is today the easy and obvious way of making wire, this has not always been so. Whatever may be the situation in regard to the softer non-ferrous metals (which sorely needs critical examination on a metallographic basis) the making of iron wire by slitting certainly persisted after, and probably preceded by many centuries, the introduction of drawing through dies. Iron is relatively hard, and primitive iron contains slag and scale which quickly destroy any but the hardest die materials, yet it is easy to hammer out a flat sheet and relatively easy to produce sharp cutting surfaces for shears. The presence of longitudinal markings on wire which are often taken as die scratches may be streaks of slag or laminations in the sheet from which the wire was slit.

There is sufficient variation between different links in the same piece of mail to raise some doubt as to the use of even the simple tools suggested by Burgess for shaping them. I incline to the opinion that hand punches and sets were used, except sometimes for the final clinching operation, for which Burgess' pliers would be appropriate. His other tools would be more at home in a nineteenth-century jeweler's shop than in one belonging to a seventeenth-century or earlier maker of chain mail.

The links display regional differences in technique and quality but no evidence of a consistent improvement in metallurgical practice over the period covered. It is remarkable that so few of the links were hardened or even hardenable. Ease of manufacture clearly took precedence over serviceability.

REFERENCES

[1] W. Burges, "Catalogue of the Exhibition of Ancient Helmets and Examples of Mail," *Archaeological Journal*, XXXVII (1880), 455-594

[2] E. M. Burgess, "The Mail-maker's Technique," *Antiquaries Journal*, XXXIII (1953), 48-55; "Further Research into the Construction of Mail Garments," *Antiquaries Journal*, XXXIII (1953), 193-202; and "The Mail Shirt from Sinigaglia," *Antiquaries Journal*, XXXVII (1957), 199-205.

[3] I believe that the production of steel by long slow heating in carbonaceous material was not a common process before the sixteenth century. Most steel faced articles could have been made by welding ostensibly uniform steel to an iron substrate. Unfortunately, metallography does not provide incontrovertible evidence, for diffusion occurs during forging and eliminates a sharp interface.

[4] Burges, *op. cit.*

[5] Burgess, *op. cit.*

ACKNOWLEDGEMENTS

Mr. S. V. Granscay started this investigation by raising questions regarding methods of manufacture of chain mail, and he kindly provided the material for study. The skilled metallographic assistance of Mmes. Betty Nielson and Stanka Jovanovic is greatly acknowledged. The work was supported in part by the National Science Foundation (Grant NSF-G7574).