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EXAMINATION OF MAIL ARMOR LINKS FROM THE METROPOLITAN MUSEUM OF ART

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Abstract

A number of solid links of mail armor were examined metallographically to determine if they had been made by stamping or by forge-welding. Although it was not possible to locate the precise position of a single weld junction, and evidence of deformation of the surface grain structure resulting from stamping would not be detectable because of severe corrosion, it was concluded that the links were made by welding on the basis of the occurrence of non-metallic inclusions in the form that would be normal in closed wire loops.

Mail armor is sometimes built entirely of drawn wire links held closed by triangular rivets, and sometimes of alternating rows of riveted and solid links. It seems to be the consensus of experts in this field that the riveted links are made of drawn wire, and according to Dr. Stephen V. Granscay, Curator of Arms and Armor of the Metropolitan Museum of Art in New York City, at whose request this investigation was undertaken and who submitted the links listed in Table I, "The mark of the drawplate is clearly visible in the wire of the riveted links." On the other hand, the method of making solid links has not been established.

The purpose of this investigation is to seek an answer to the following questions asked by Dr. Granscay:

(1) Were the solid links made by stamping or were they individually welded?

(2) Are the links laminated?

(3) Do the solid links show marks of the drawplate?

Standard metallographic procedure was used in theexamination of the links, they were individually mounted in bakelite, ground to approximately one half of their thickness, given a metallographic polish, etched with a suitable reagent and examined microscopically at low and high magnifications.

The evidence sought to decide if a solid link had been made by stamping was the occurrence of a layer of deformed grains along the inner and outer circumference of the link. This would constitute valid proof of stamping, because when a soft, ductile metal, such as the iron of which these links are made, is severed cold, it is inevitable that those grains which come in contact with the cutting edge will suffer severe deformation. Figure 1 illustrates the deformation caused by punching a hole in a sheet of low carbon steel. It is true that deformation of the surface metal also occurs during wire drawing, if done cold, but if such deformed grains are subsequently heated, as is necessary for welding, all traces of cold deformation are obliterated. The links illustrated in the accompanying photomicrographs, and others not photographed, were examined for traces of deformation of the metal at the surface and in no instance was satisfactory evidence found to justify the conclusion that the links was made by stamping. Unfortunately, these negative results do not, in themselves, eliminate stamping as a possible method of manufacture, for the pitted condition of the surface metal suggests that during their long existence these links had corroded severely enough to eat away all traces of the original surface metal. Moreover, if the links had been stamped and subsequently forged hot, any evidence of cold work would be destroyed.

The criterion employed to decide if a links had been made by welding was the presence of certain discontinuities in the structure of the metal which can be expected to occure in the vicinity of the junction as a result of welding. Among such discontinuities, those most often met are (1) localized, marked grain growth; (2) evidence of melting, or of incipient melting; (3) more or less continuous line of oxide inclusions, or of voids, normal to the direction of drawing. Figures 2 and 3 illustrate two of these discontinuities in a modern pressure weld, which is the closest approximation to a blacksmith weld that was available. Unfortunately, no links disclosed evidence that could be construed as valid proof of welding. Some links did exhibit decided differences in grain size from area to area, but these were scattered at

random and often their shape and size did not convey the impression of being the result of welding. The nearest approximation to the type of grain growth often observed near a weld junction is illustrated at the top and bottom of Figure 4. However, although suggestive of welding, this is not sufficient evidence to warrant a categorical statement.

While it has not been possible to prove by positive identification of a weld junction that the links were closed by some form of welding, it is the writer's belief that welding was the only method of manufacture employed. This belief is based on the following observations.

(1) The stringers of non-metallic inclusions curve with the link as is clearly shown in Fugures 5 and 6. Had the links been stamped from a flat sheet, the inclusions would occur in straight lines, as illustrated in the sketch, Figure 7A. The fact that they occur as shown in Fugure 7B is strong evidence that the metal was drawn into wire before it was closed to form a link.

(2) Examination of several riveted links showed that their non-metallic inclusions also curved with the links, confirming the assumption that the riveted links were made of drawn wire, and strengthening the belief that the solid links had also been made from similar wires.

(3) It seems reasonable to assume that had the solid links been stamped from a flat sheet, the surfaces corresponding to the top and bottom of the sheet would tend to be somewhat flatter than the corresponding surfaces in the riveted links. Such has not been observed to be the case. On the average all the links appear to be equally round. However, the possibility that the armorer may have known how to stamp round, wire-like links from a flat sheet cannot be ignored. Figure 10 shows the similar degree of roundness of the wire in a riveted and a solid link from the same shirt of mail.

Figure 11 illustrates the micrstructure of link number 29-150-9V and Figures 12 and 13 that of link number 14-25-1555. These links differ radically from all others in two respects; they contain more carbon than the average link and they were probably water quenched. The grey, finely divided areas shown in the photomicrograph of link number 29-150-9V (Fig. 11) were identified as martensite, a constituent of steel of great hardness and obtainable in an unalloyed steel containing

an appreciable amount of carbon by very rapid colling, such as water quenching. It is estimated that this link was quenched from a temperature in the vicinity of 1400 F. The structure of link number 14-25-1555 (Figs. 12 and 13) also indicates a considerable amount of carbon and a rapid quench, bu inaddition this link was tempered at some temperature that is not possible to estimate. Because these links contain an appreciable amount of carbon and were cooled rapidly they are much harder than the other links. See Table II.

The question whether or not a link is laminated is of relatively little significance but difficult to answer. If the metal contains a considerable amount of stringers of non-metallic material (probably occluded slag) it may be said to be laminated; if the non-metallic inclusions are fewer, shorter, and well scattered, the metal does not appear laminated. It is difficult to draw a dividing line. Some of the links examined showed considerable occluded slag, others much less, as may be seen by comparing Figures 14 and 15 with Figures 5 and 6 and Figures 8 and 9. Large areas of the irons illustrated in Figures 14 and 15 are “clean” (free from non-metallic inclusions) even when judged by modern standards.

Figure 16 was obtained from link No. 27.183.14 and shows a group of Neumann bands. This structure, also referred to as “mechanical twins” is generally associated with a metal that has been subjected to severe impact or to deformation at relatively low temperatures. It is most likely that these bands were made by the armorer while cold-hammering the metal but it is also possible that they were produced by a healthy blow in battle, or in handling.

Several riveted links and all the solid links were examined with a low power microscope for marks of the drawplate. None that could be positively identified was detected, but it may well be that although present they were not recognized or that they had been removed by corrosion of the surface.

*NOTE - FIGURES 14, 15 & 16 WERE LEFT OUT DUE TO THE PICTURES BEING TOO PALE TO SHOW ANY DETAIL.

Summary and Conclusions

(1) Detailed macro- and microscopic examination of the solid links submitted by the Metropolitan Museum of Art failed to disclose a recognizable weld or evidence of deformation of the surface metal associated with stamping.

(2) The fact that the non-metallic inclusions in the solid links are stretched out and curved as they would be in a loop of wire, is considered conclusive evidence that the solid links were closed by welding.

Table I

Chain Mail Specimens Submitted

Designation	Description
27.183.14	Brayette. German, about 1525 Solid and riveted links (riveted, flat wire; solid, half round wire)
29.150.9V	Shirt of mail. German, about 1500 Solid and riveted links (solid link, half round; riveted link, flat)
14.25.1568	Shirt of mail. German, about 1500 Solid and riveted links (riveted, flat wire; solid, half round)
14.25.1555	Shirt of mail. German, about 1525 Solid and riveted links (riveted, flat wire; solid, half round)
54.46.2	Shirt of mail. German, about 1525 Riveted links (flat wire)
25.188.9	Shirt of mail. German, about 1550 Riveted links (flat wire)
29.158.176	Shirt of mail. German, about 1575 Riveted link (round wire)
27.237	Shirt of mail. German, about 1575 Riveted link (round wire)
14.25.1539	Cape of mail. German, about 1575 Riveted link (round wire)
36.25.33	Shirt of mail. Turkish, 17th Century Solid link and double riveted link (Flate wire in both cases)
14.99.28	Shirt of mail. Turkish, 17th Century Solid and riveted links (moulded section)
14.25.1562	Shirt of mail. Persian, 18th Century Solid and riveted links (round wire)
36.25.476	Shirt of mail. Persian, 18th Century All riveted links (round wire)
Coif	Rare XIV Century European Headpiece

Table II

DPH Hardness - 100 Gm. load
(Arranged in order of increasing hardness)

Link No.	Hardness*	Remarks
27-183-14	143	Riveted - near rivet
	156	Riveted - opposite rivet
14-25-1568	156	
36-25-33	176	Contains Sheroidal carbides
Walters Coif	190	
17-183-14	193	Solid Link
14-25-5162	234	
14-99-28	276	
29-150-9V	355	Partly martensitic
14-25-1555	468	High carbon - Tempered martensite

* Average of at least three readings.

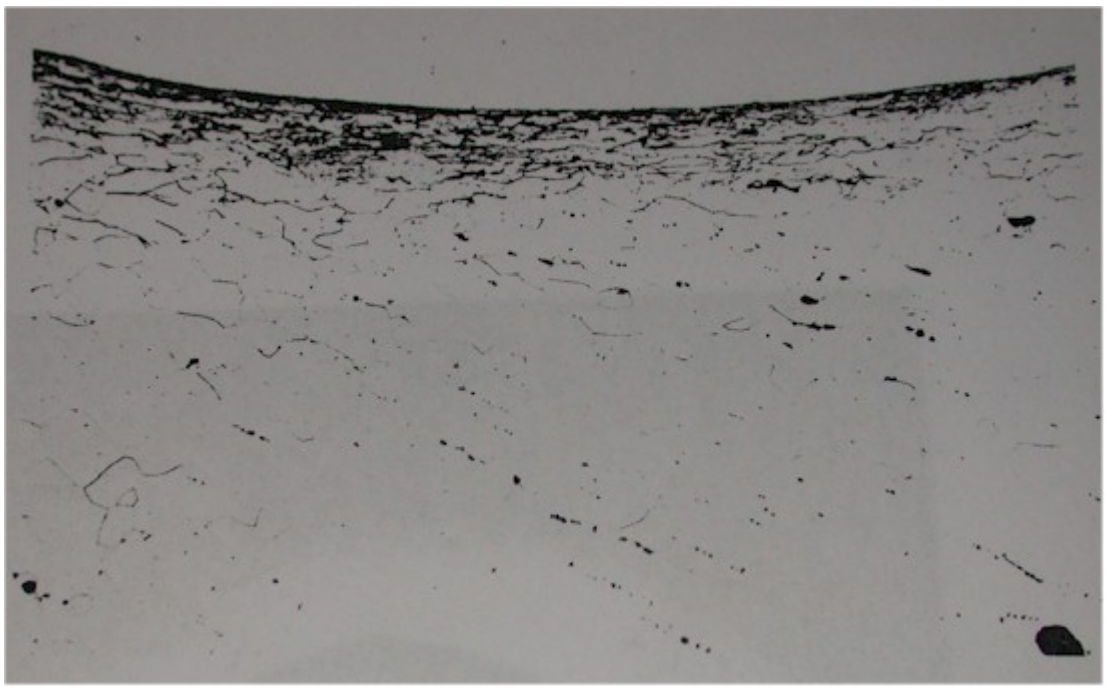

FIG. 1 -- DARK CURVED BAND SHOWS DEFORMATION OF GRAIN STRUCTURE IN LOW CARBON STEEL ALONG EDGE OF HOLE PUNCHED IN SHEET. PICRAL ETCHED - X200

FIG. 2 -- WELD JUNCTION IN MODERN PRESSURE WELDED PIPE - ETCHED WITH 25% $NaHSo_3$ - X30

FIG. 3 -- SAME WELD AT HIGHER MAGNIFICATION. NOTE OXIDE GLOBULES INDICATING JUNCTION. LIGHT PICRAL ETCHED - X200

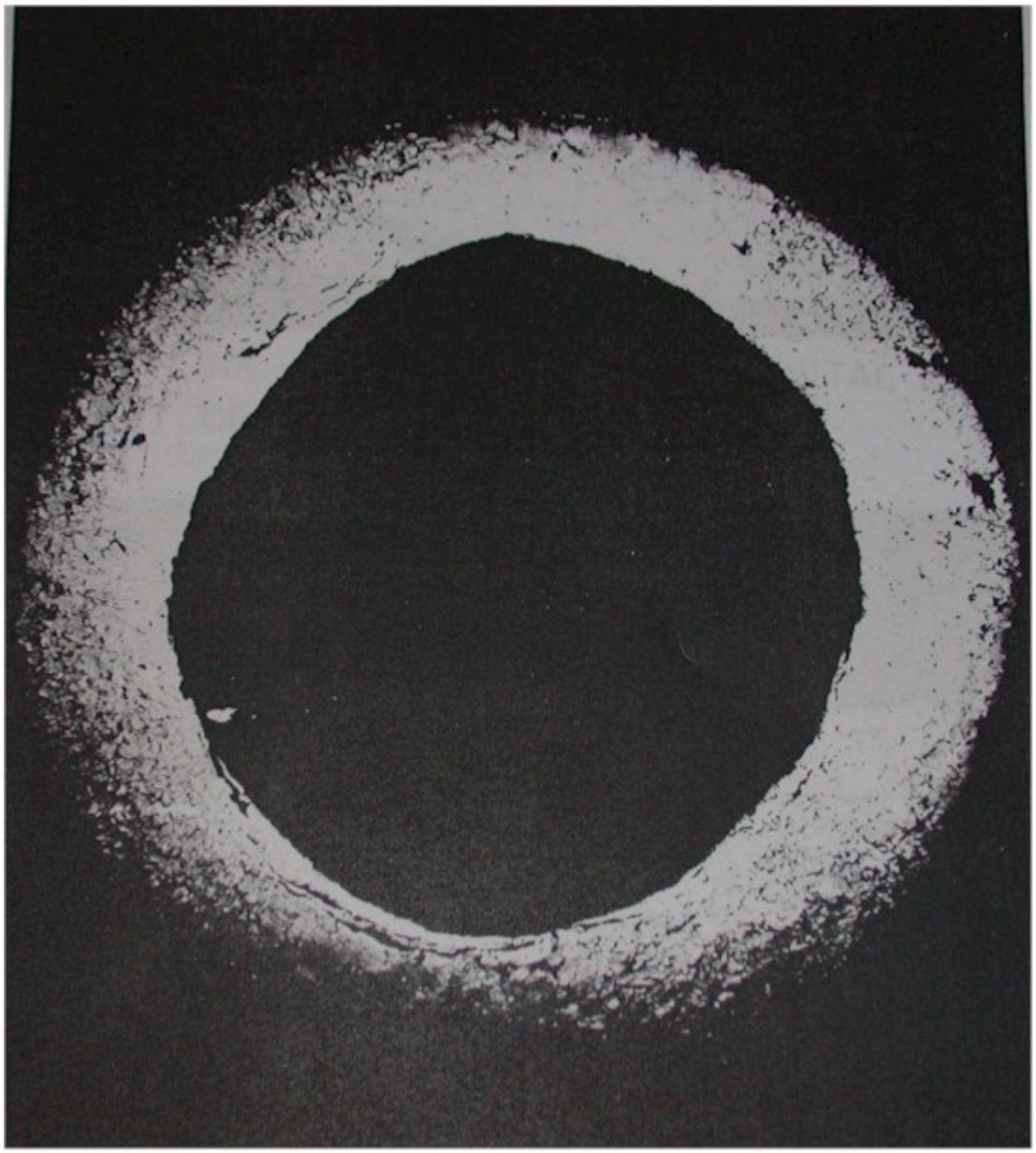

FIG. 4 -- SOLID LINK, 27-183-14, X 13 GERMAN-BRAYETTE, ABOUT 1525.

FIG. 5 -- SOLID LINKS - 14-25-1568, NITAL ETCH - X100
GERMAN SHIRT OF MAIL, ABOUT 1500

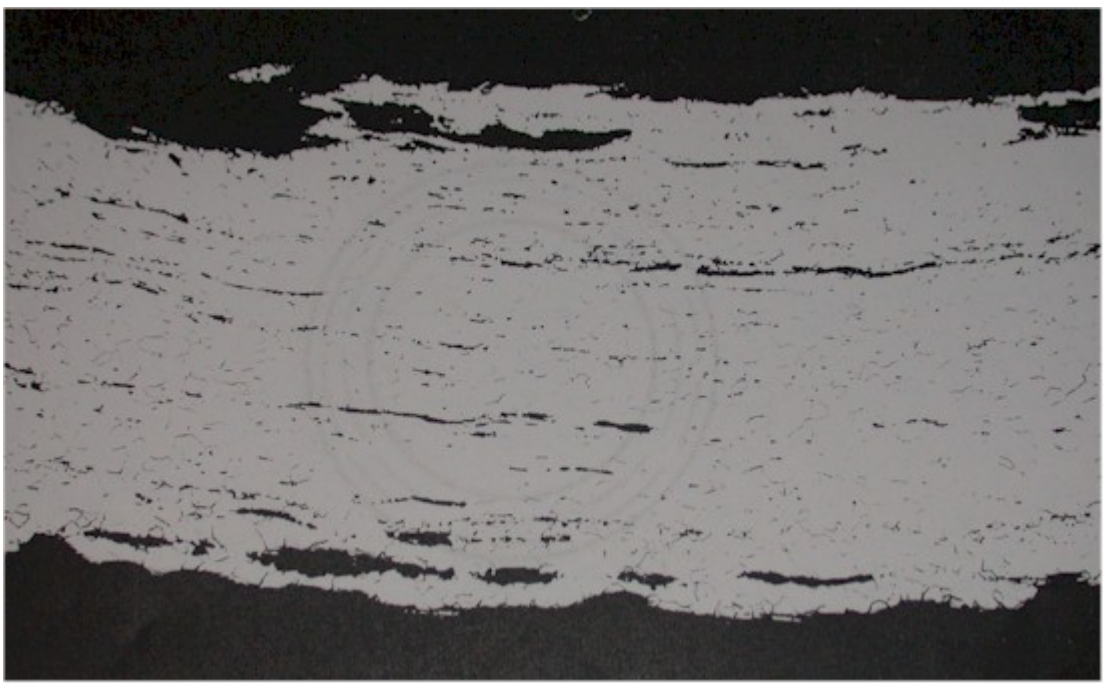

FIG. 6 -- SOLID LINK - COIF NITAL ETCH - X100

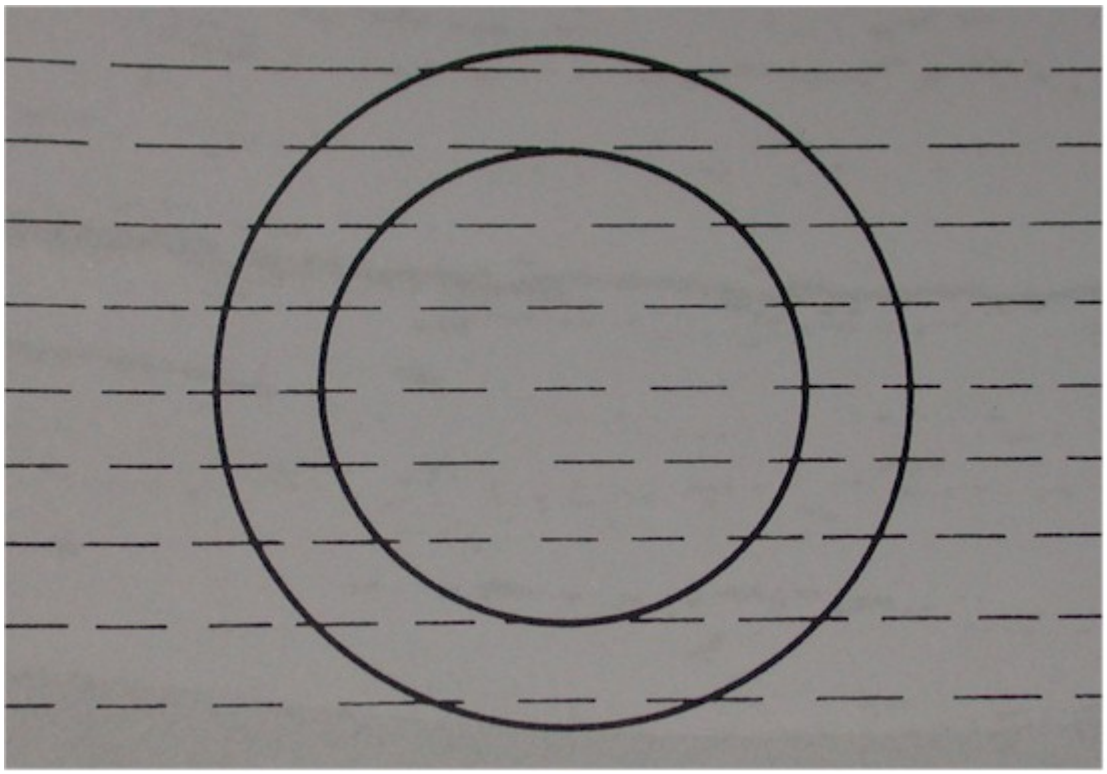

FIG. 7A - OCCURRENCE OF NON-METALLIC INCLUSIONS EXPECTED IN STAMPED LINK

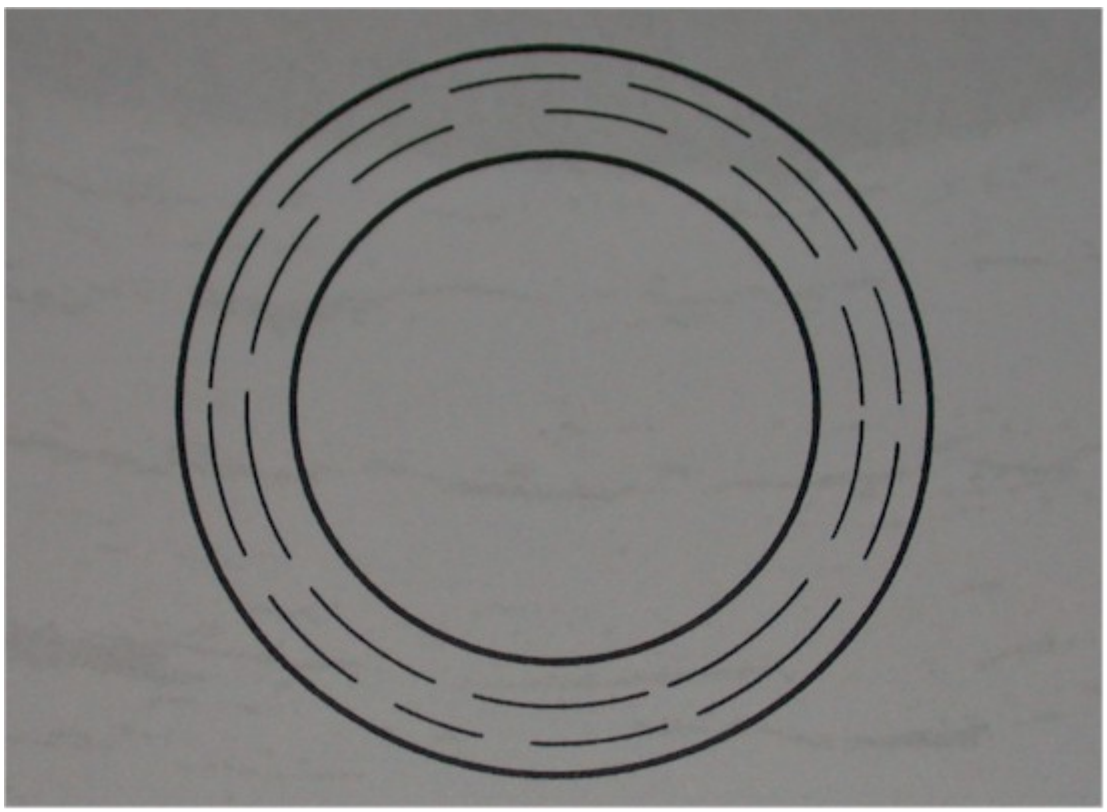

FIG. 7B - OCCURRENCE OF NON-METALLIC INCLUSIONS EXPECTED IN WELDED WIRE LINK

FIG. 8 -- RIVETED LINK - 14-25-1568 X50
GERMAN SHIRT OF MAIL, ABOUT 1500

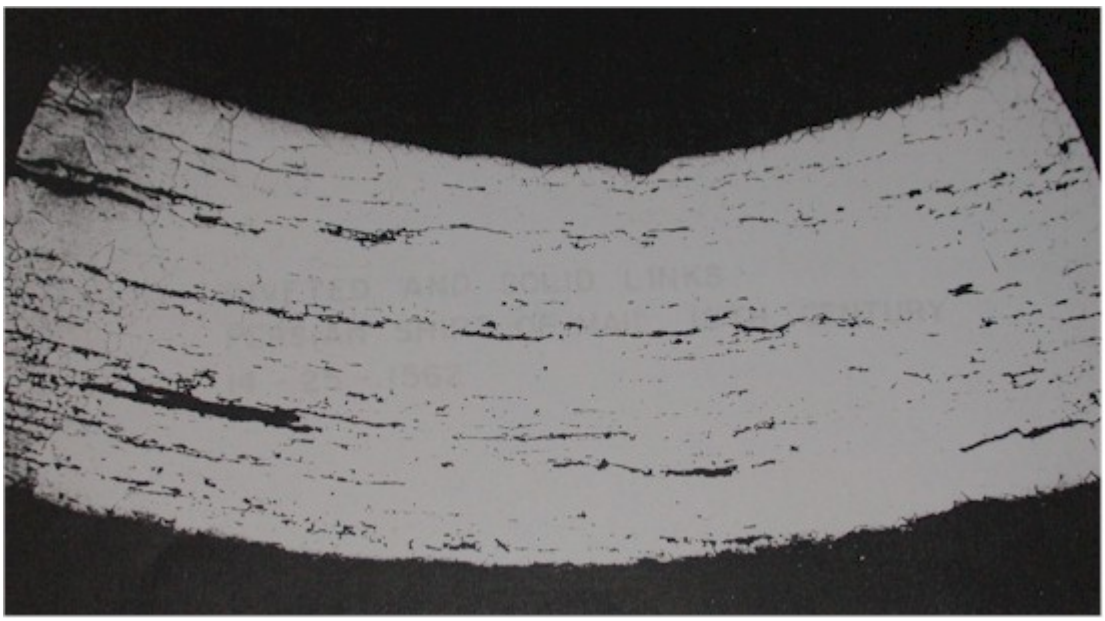

FIG. 9 -- RIVETED LINK - 27-183-14 X50
GERMAN BRAYETTE, ABOUT 1525

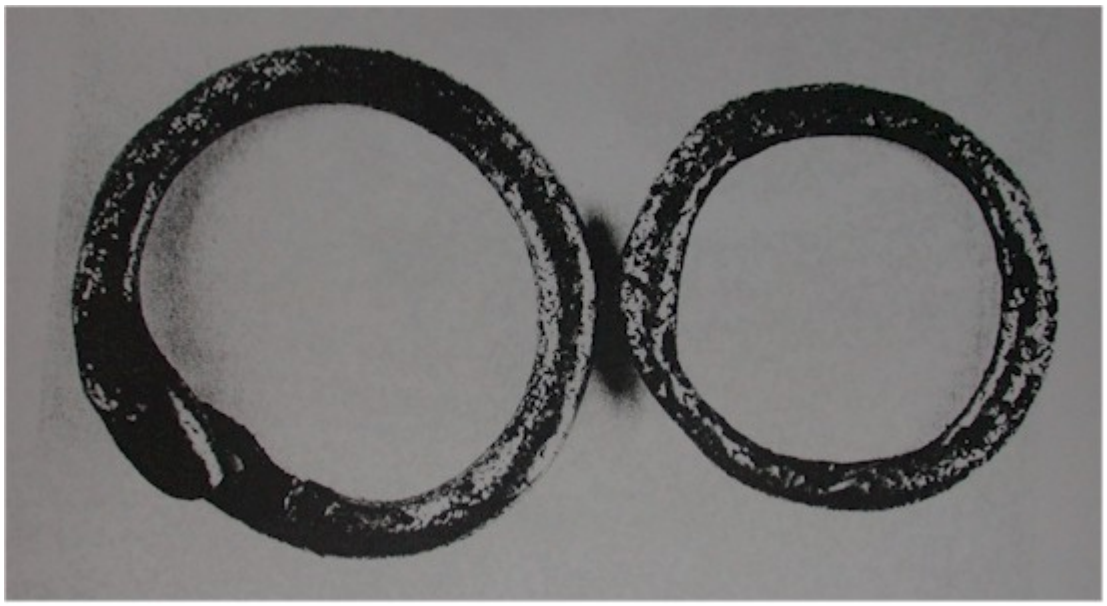

FIG. 10 -- RIVETED AND SOLID LINKS X5
PERSIAN SHIRT OF MAIL, 18TH. CENTURY 14-25-1562

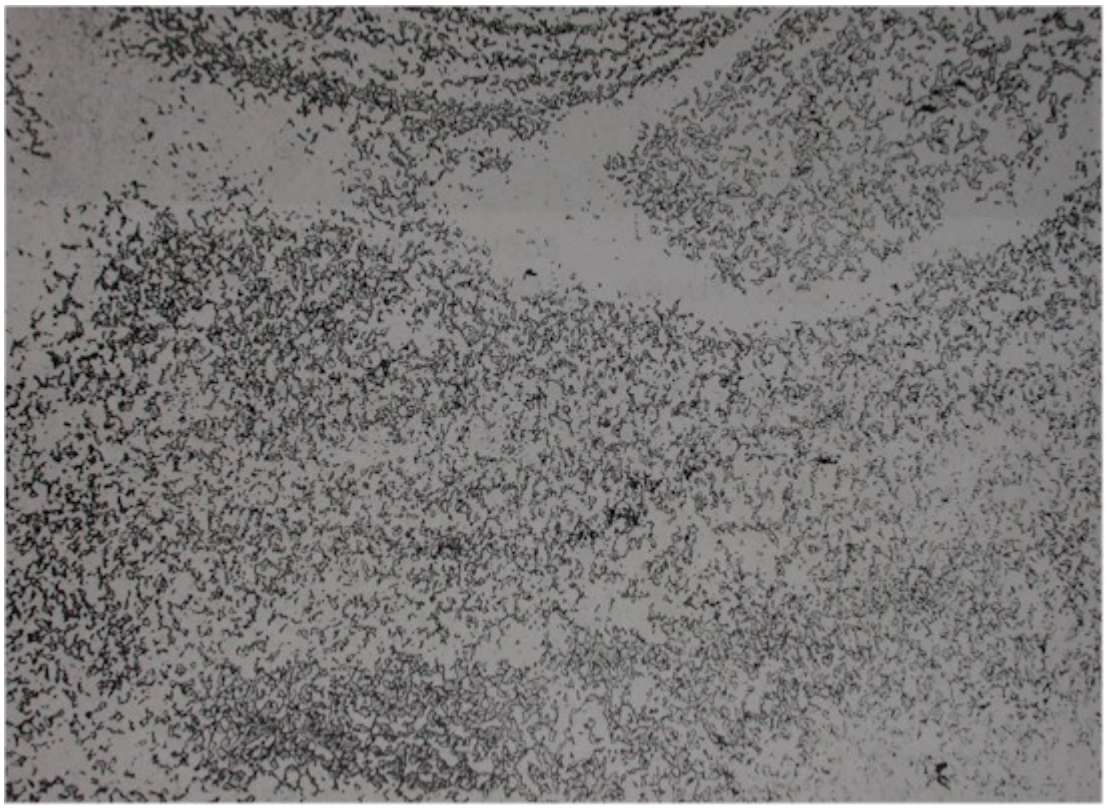

FIG. 11 -- SOLID LINK 29-150-9V PICRAL ETCHED X100
GERMAN SHIRT OF MAIL, ABOUT 1500

FIG. 12 -- SOLID LINK 14-25-1555 PICRAL ETCHED X100
GERMAN SHIRT OF MAIL, ABOUT 1525

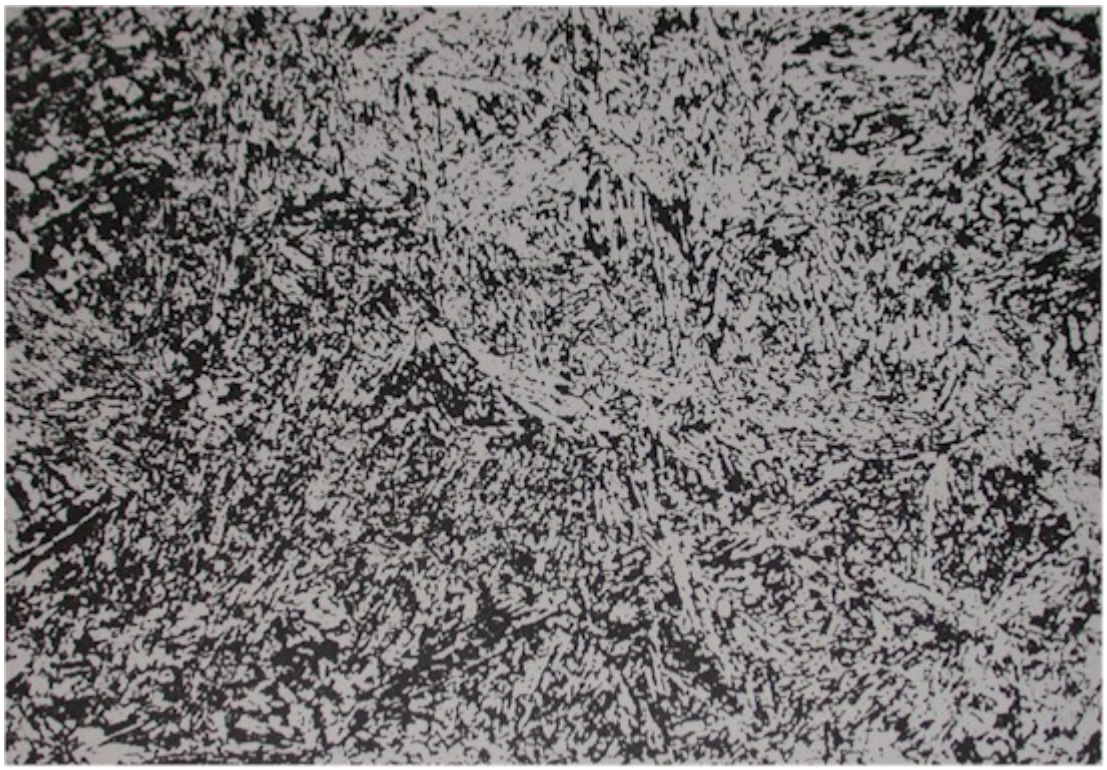

FIG. 13 -- SAME AS ABOVE X2000