

1976

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Berger, J. Alfred; Hawks, Catherine A.; and Grimm, Jacob L. (1976) "The Metallurgical Study of Fort Ligonier Bayonet Sections, Hand Forged Spikes, and Copper Powder Keg Hoop Sections," *Northeast Historical Archaeology*: Vol. 5 5, Article 4. <https://doi.org/10.22191/neha/vol5/iss1/4> Available at: <http://orb.binghamton.edu/neha/vol5/iss1/4>

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The Metallurgical Study of Fort Ligonier Bayonet Sections, Hand Forged Spikes, and Copper Powder Keg Hoop Sections

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This paper represents the first in a series of presentations covering information acquired from the metallurgical study of many different types of artifacts from Fort Ligonier, Ligonier, Pennsylvania, that were made available to the author for microscopic and chemical analyses. It is hoped that such investigations will assist the archeologist in identifying the kinds of material and the methodology which were used to make the artifacts at Ligonier and at sites of similar antiquity. Since the artifact fragments studied had to be cut, the macro and micro metallographic specimens will be displayed along with the actual artifacts at the Fort Ligonier museum.

The three types of artifacts discussed in this paper represent three distinct kinds of materials, namely, forged steel found in bayonet blade sections, wrought iron containing slag found in hand forged spikes, and deoxidized copper found in rolled powder keg hoops. Additional processing techniques like the forge weld joining of the steel bayonet blade to the wrought iron retaining sleeve on the "Brown Bess" musket barrels; the iron silicate slag stringers and non-metallic inclusions observed in wrought iron spikes, and the copper oxide eutectic found in cast, cold-worked copper rivets used to join together the copper bands that restrained oak powder keg barrel staves, disclose interesting information regarding the prerevolution manufacturing techniques employed by the various craftsmen responsible for producing the artifacts found at Fort Ligonier.

BAYONET METALLURGICAL INVESTIGATIONS

Metallurgical samples for chemical analysis and

microanalysis were cut from two "Brown Bess" Bayonet sections identified as 47-1-652 and 69-1-31. The 47-1-652 fluted triangular fragment approximately 6" in length, provided sample stock for the early heat treating and microscopic tests. Preliminary chemical analytical results indicated that this bayonet was made from a plain carbon, unalloyed, .75%C eutectoid steel having a very fine fracture grain size (P-F no. 7). Transverse microspecimens were cut from the triangular blade section and subjected to various heat treating operations like water quenching followed by tempering, oil hardening, air cooling (normalizing) and furnace cooling (annealing) in an effort to simulate the type of microstructure observed in the "as-received" blade section which had been buried since 1758. Hardness tests and micro results on the badly corroded bayonet fragment indicated that the blade had not been quenched and tempered but subjected to a normalizing (air cooling) type of heat treatment. These interesting preliminary results prompted the request for additional specimens for visual examination, and one of the more intact complete bayonets 72-1-396 was studied in detail then returned for display while a lower bayonet portion 69-1-31 approximately 10" in length was retained for metallurgical sectioning, chemical analysis, and microstructure metallographic investigation.

The lowermost blade section of bayonet 69-1-31 was triangular in shape having a fluted maximum width of 1-1/4", and the cross section was approximately 1/2" in thickness. The base of the bayonet had been forged into a 3/8" round and bent with a 3/4" radius into a right angle shape which was joined to the sleeve at a distance of about 1-3/4" from the central bore of musket

barrel axis. The end of the circular section was upset and the flange forge welded to a tapered wrought iron cylindrically shaped sleeve (4" long \times 15/16" internal diameter \times 3/32" wall thickness) that contained a slot so that it could be slipped over the front sight of the musket and locked into position on the end of the "Brown Bess" musket barrel with a clockwise motion that engaged and secured the retaining slot. This allowed the bayonet to be rigidly fastened to the rifle.

This bayonet section shows an excellent example of forge welding the tough "normalized" high carbon steel blade (.80%C) as it is joined permanently to the ductile low carbon (.05%C) wrought iron bayonet mounting sleeve or cylinder made by the hand puddling process. The microstructure of the wrought iron sleeve is similar to that which will be presented later for the hand forged wrought iron spike; the sleeve had a hardness of 56 Rockwell "A" (84RB, 162 BHN; conversion hardness values).

It is interesting to note that in 1740 just prior to the time of Fort Ligonier, an English watchmaker named Huntsman and one of his apprentice sons, while searching for better clock springs, are

usually credited with the discovery of the crucible steel making process.

Metallographic examination of all the bayonet sections tested clearly indicate that the bayonet blades are not made from "blister steel" but possess the uniform composition of high carbon crucible steel that has been cast and subsequently hammer forged into the fluted, tapered blade which in the as excavated condition possesses Rockwell "A" hardness values of tough, "normalized" microstructures varying between 68RA to 71RA (35RC 322 Brinell, Hardness No. 157000 pounds per square inch, tensile strength; to 41RC 382 B. H. No. 188000 psi tensile strength). The microstructure at 500 diameters (500X) for an "as received" (as excavated) bayonet cross section is shown in Figure 1.

Note the exceedingly fine pearlite dark gray lamellar structure and the dispersed cementite phase (the white Fe₃C or iron carbide islands) from the forging operation after the blade was cast, forged, and heat treated by heating above 1500°F and rapidly air cooling this eutectoid .80% Carbon steel to produce the moderately hard-tough steel.

Small samples cut from the blade section, on



500X Magnification
70RA Hardness

Picral Etch

Fine Pearlite Matrix (dark gray area) and Cementite
(Fe₃C-iron carbide white islands)

Figure 1. Bayonet 69-1-31 microstructure in the "as received" condition.

Table 1
Some Heat Treating Data Obtained from 1/4" Thick 69-1-31 Bayonet

Sample	Treatment	Average Hardness Values		
		Rockwell "A"	Conversion Rockwell "C"	Conversion Brinell Hardness No.
1	1650°F Austenitize, then water quenched	84.0	65	745
2	1550°F Austenitize, then oil quenched	82.5	62	698
3	1675°F Austenitize, then air cooled (normalize)	72	43	397
4	1650°F Austenitize, then furnace cooled (full anneal)	66	31	294
5	1650°F Austenitize, water quenched, double tempered at 800°F	71	41	379

the cut off wheel, which were heat treated in modern furnaces under controlled conditions gave the following hardness data upon which the surmised foregoing bayonet heat treatment is postulated.

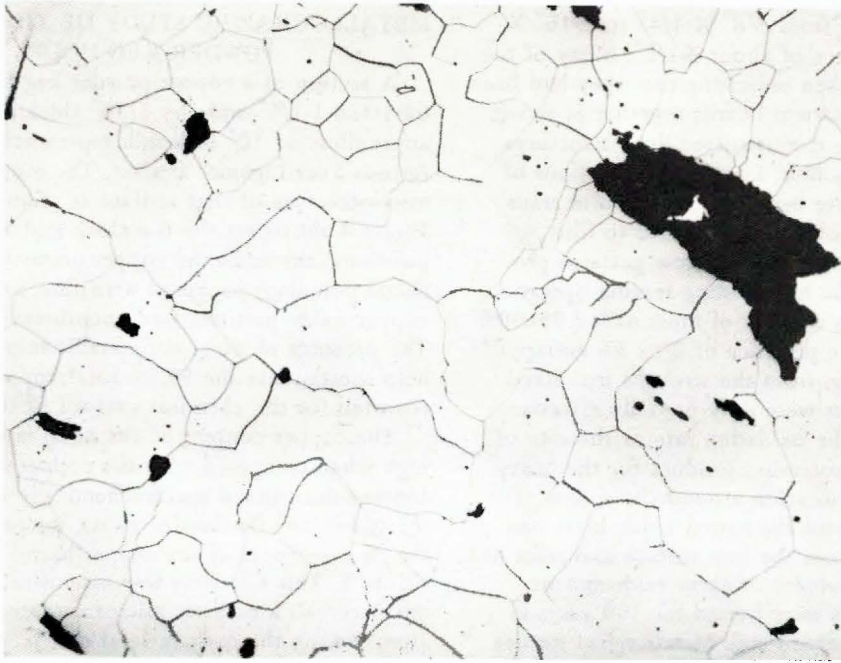
To obtain the toughest, hardest microstructure for a steel of this composition, a modern gunsmith would resort to a solution treating austenitizing temperature around 1600°F in an electrically heated atmosphere controlled muffle or tube furnace, followed by a water or oil quench and single or double tempering around 600 to 800°F. This would produce a tempered martensite (needlelike-lightly etching) microstructure; however, this structure was not observed in any of the bayonet samples examined metallographically after mounting in lucite, rough polishing on 240, 320, 500, 600 grit wet silicon carbide paper, then final polishing with 1 micron and .05 micron Linde "B" alumina prior to etching with either 5% Nital (5% HNO₃ in ethylalcohol) or 3% Picral (3% Picric Acid in ethyl alcohol). The microstructures observed from different areas on several of the bayonet sections available for micro testing from Fort Ligonier (47-1-652 and 69-1-31) do not reveal any tempered martensite microstructure but do have fine pearlitic matrices with some dispersed iron carbides that correspond to normalized heat treatments (which seem plausible for the 1740/1750 gunsmith would not have furnaces readily available for uniformly heating the long thin bayonet blades) after heating in the charcoal forge.

METALLOGRAPHIC STUDY OF HAND FORGED SPIKES

The microstructure and hardness data obtained on all of the iron nails examined to date indicate that they were manufactured from wrought iron using a hotheading operation on the nail forming block. The wrought iron used as stock material for the nails could have been made by the colomists; however, the amount and distribution of the ferrous silicate (FeO)_x · (SiO₂)_y slag indicate that the material probably was made by the "wet" hand puddling process where the non-metallic iron silicate slag is distributed as parallel slag stringers in longitudinal micro sections and as irregular circular shaped nonmetallics in transverse micro sections. These observations are clearly shown in the photomicrographs of Figure 2 and Figure 3.

Hardness data obtained on the two micro samples varied considerably from 31R_A (41 R_B75BHN) on the relatively soft longitudinal specimen of Figure 3 to 94R_A (84R_B 162BHN) for the transverse micro section shown in Figure 2. The great variation in hardness determinations of the ferrite wrought iron matrix may be partially explained by the hot-cold nail upsetting or heading operation and the amount and extent of the recrystallization which occurred after the nail was made and put in service.

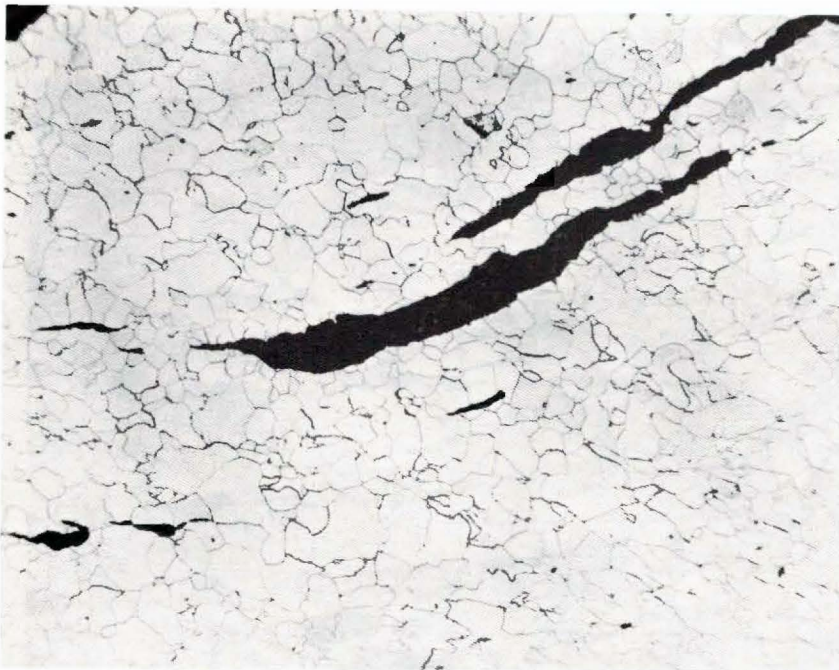
Most of the spikes found during the excavation had large square "rose" or pyramidal type heads, approximately 1-1/4" square, upset by a hot heading-forging operation on rectangular nail



500X Magnification

5% Nital Etch

Figure 2. Transverse micro sample of powder bastion spike 64-1-382 showing ferrite matrix (white grains) and the iron silicate slag $(\text{FeO})_x(\text{SiO}_2)_y$ -the dark gray areas.



250X Magnification

5% Nital Etch

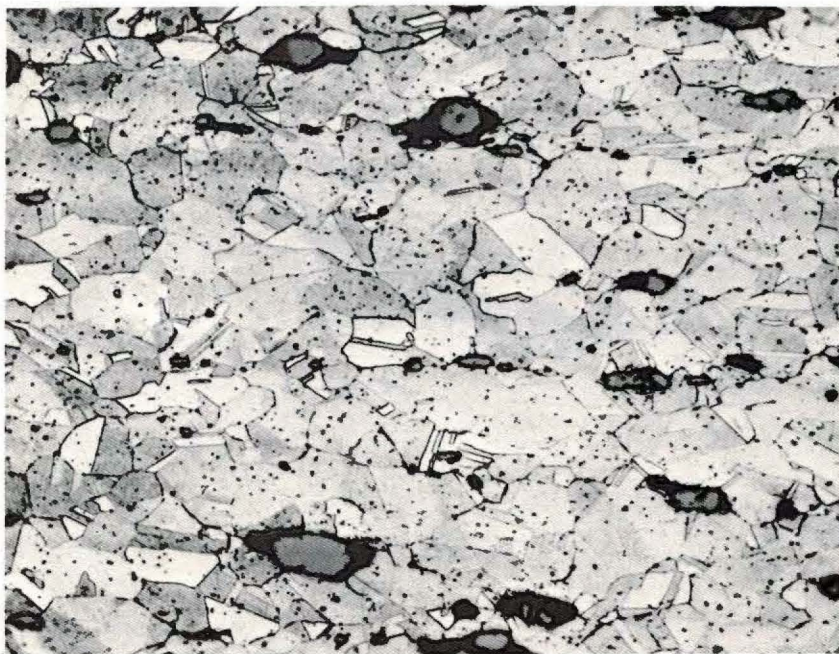
Figure 3. Longitudinal two phase iron silicate slag stringers $(\text{FeO})_x(\text{SiO}_2)_y$ -gray and black areas in the ferrite matrix near the shank-head interface of spike 64-1-832.

shanks tapering from $3/8'' \times 1/4''$ to $3/16'' \times 1/8''$ in a distance of about $3-1/2''$. Many of the nails were clinched indicating that they had been used to fasten several boards together as shown on many of the reconstructed door structures within Fort Ligonier. Longitudinal sections of entire spikes have been cut, mounted in transparent resins, polished and etched to illustrate the ferrite and slag stringer flow patterns produced during the hot heading forging operation. The low carbon content of most nails (.03-.08% Carbon) and the presence of 2 to 3% entrapped iron silicate slag, from the wrought iron hand puddling process were only partially effective in controlling the oxidation rate or the rate of growth of the corrosion product for the heavy iron oxide encrustation around the spikes, revealed areas where the rusted oxide layer had broken away from the iron surface and reformed during the movement of earth environment while the spikes were buried for 200 years in the moisture laden soil. Metallurgical studies on other iron artifacts like wheel rim, wagon hardware and fasteners, knives, axes, and tools could compliment these studies if the artifacts are present in sufficient quantity to permit destructive micro and chemical analysis on duplicate specimens.

METALLOGRAPHIC STUDY OF THE COPPER POWDER KEG HOOP

A section of a copper powder keg hoop No. 62-1-328 $1-1/6''$ wide by $1/16''$ thickness by approximately $10''$ in length represents a non-ferrous Fort Ligonier artifact. The longitudinal microstructure of that artifact as pictured in Figure 4 shows (at the 6 o'clock and 12 o'clock positions) the equiaxed copper grains (with occasional twinning) peppered with fine, numerous copper oxide particles (gray nonmetallic phases). The presence of these nonmetallic impurity phases help substantiate the 99.2% total copper content reported for the chemical analysis of this material.

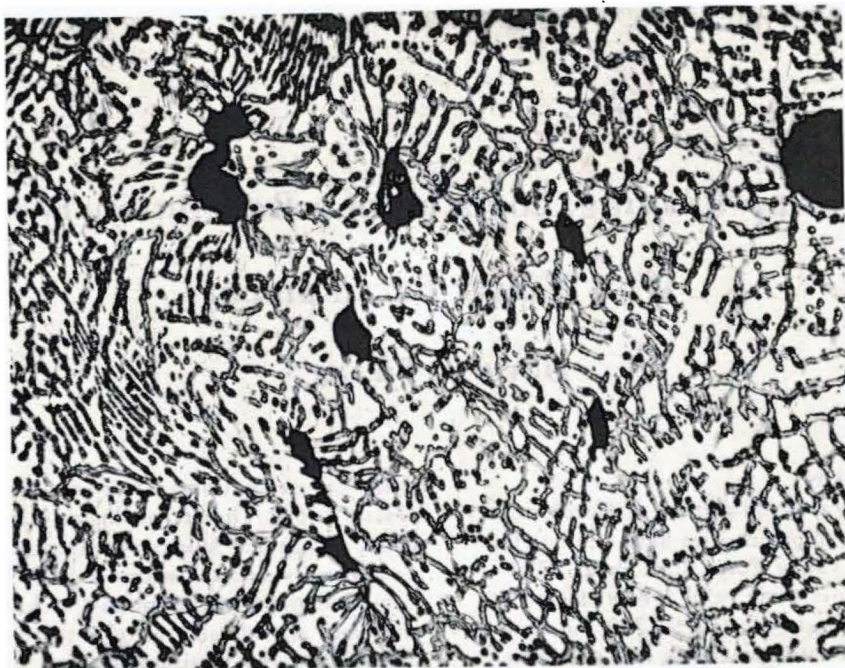
The copper content of the hoop is relatively high when compared with the copper and oxygen content determined spectrochemically on one of the two $3/16''$ flat-headed rivets, micro forming, the two segments of the copper barrel hop in Figure 5. This relatively low magnification (100X) micro reveals a eutectic microstructure (1.54 atom % O_2), the dark skeletal matrix, and some large black copper oxide (Cu_2O) particles which account for the 98.5% total copper analysis. The eutectic structure also shows conclusively that the rivets were cast prior to being used and not formed from wrought copper rod stock. It is indeed surprising that the rivetheads did not crack



250X Magnification

NH_4OH -Glycerol Etch

Figure 4. Copper hoop matrix of equiaxed copper grains, small copper oxide eutectic particles and large copper oxide (Cu_2O) nonmetallic inclusions (dark gray-black islands).



100X Magnification

NH₄OH-Glycerol Etch

Figure 5. Barrel hoop rivet microstructure showing copper oxide eutectic (gray skeletal forms) and copper oxide nonmetallic inclusions (dark gray particles).

and split more than noticed when considering the composition of the cast copper rivets. As a passing comment it may be worth noting that the quality of some of the wrought and cast material of the Palestinian and Egyptian eras had less oxygen content (fewer nonmetallic copper oxide inclusions) and better quality than that observed in the copper hoop and cast rivets. Since I have

been unable to locate any references in the literature that copper was reduced from the ore, cast, and rolled into bands by the colonists, it seems fruitless to speculate whether or not the hoop metal was produced in America or in Europe where the manufacturer could have learned some tricks about the deoxidation of copper from the ancient copper and bronze age metal smiths.