2nd International Conference

ARCHAEOMETALLURGY IN EUROPE 2007

17-21 June, 2007

Aquileia · Italy

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Friuli Venezia Giulia — *Ospiti di gente unica*

ISBN 88-85298-71-0

Published by

ASSOCIAZIONE
ITALIANA DI
METALLURGIA

I – 20121 Milano
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USE - WEAR ANALYSIS ON METAL: THE INFLUENCE OF RAW MATERIAL AND METALLURGICAL PRODUCTION PROCESSES

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ABSTRACT

The study of use-wear on metallic instruments is still on a starting phase. The results presented here come from experiments on pure copper and bronze (5 and 15-17% tin) worked with combinations of different processes, like for instance the metal was as forged cold and annealed. We must consider the influence exerted by these variables in the formation and identification of use-wears. The complexity of the experiments leads us to focus initially on a limited number of objects characteristics of the first metallurgical phases (Chalcolithic and Bronze Age).

Keywords: use-wear analysis, functionality, experimentation, post-casting treatments, raw material, archaeometallurgy, Copper and Bronze Age.

La aplicación del estudio de huellas de uso sobre instrumentos metálicos está aún en su fase incipiente. Los avances que presentamos son el resultado de una experimentación sobre cobre puro y bronces al 5 y 15% de estaño, trabajados con distintas combinaciones de procedimientos como forja en frío y recocido. Tratamos de determinar la influencia de estas variables en la formación e identificación de las huellas de uso. La complejidad de la experimentación nos ha inducido a trabajar inicialmente sobre un reducido número de instrumentos característicos de las primeras fases metalúrgicas (Calcolítico y Bronce antiguo-pleno).

Palabras clave: análisis traceológico, funcionalidad, experimentación, tratamientos postfundición, materia prima, arqueometalurgia, Edad del Cobre y del Bronce.

INTRODUCTION

This study deals with the application of Traceology —use-wear analyses— to metallic objects. This methodology was initiated by Semenov (1964) [1] and it aroused interest in the Western world since the 70's [2]. Although it has been applied almost exclusively to the study of flint and bone tools, there have been published some specific papers studying the function of metallic tools during the recent years. Some of these papers approached to the issue through experimentation [3-9] and some others focused on the detection of use-wear traces on archaeological objects [10-17].

Scarce experimentation has been done up to now and its results are difficult to apply to the study of large sets of objects, due mainly to a poorly defined experimental protocol that does not allow to isolate the different variables involved (raw material, time of work, worked material, etc). Actually, most of the experiments have focused mainly in the functional response of the tools rather than in checking the different variables implicated in the process.

OBJECTIVES

Our main objective is the knowledge of the function of prehistoric metallic tools. In order to define this objective, we must be able to distinguish the patterns created by use, that is to say, use-wear traces, from those produced during the metallurgical and post-depositional processes or the conservation-restoration treatments. Moreover, we must consider the influence exerted by essential variables, such as raw material and the several metallurgical processes that changes the mechanical properties of the tool (annealing, forging).

Regarding this subject, and as a part of a more broad project, we have designed a restrict experimental program intended to verify the effects that raw material and metallurgical post-casting treatments have had on the quantity and quality of use-wear traces in metallic material. Both factors have shown to produce considerable variations in use-wear traces in flint tools [18].

METHODOLOGY AND EXPERIMENTAL WORK

Table 1 presents the report of experiments focused on raw material and post-casting treatment that have been performed with two selected kinds of tools: knife-daggers and flat axes. These implements are very characteristic of Iberian prehistoric metallurgy. Both tools were experimentally produce employing three different kinds of raw material: pure copper, 5% tin bronze alloy and 15-17% tin bronze alloy. The composition of all these tools has been analyzed by X-ray fluorescence spectrometry (XRF) in order to verify possible losses of tin occurred during smelting [19]

The metallic tools were melted in a open furnace provided with electrical ventilation and charcoal using a small graphite crucible covered with a lid. In this point, our objective was not to reproduce the prehistoric process of metal production but the mechanical properties of metallic tools obtained. It has been recently proposed that, apart from the often recovered stone and clay moulds, sand moulds, which could have disintegrated completely after use, were also used [20-22]. In our experiments we tested this assertion pouring the metal in a preheated compacted sand open mould. We used the *foundry sand* employed commonly in industrial foundry which has a perfect mixture of sand, clay and moisture content (2-3%).

Nº	Tool	Raw material	Post-casting treatment	Work	Time of Work	Worked material
22B	Knife-dagger	Copper	CF+S	Cutting	1 hour	Animal carcass
23B	Knife-dagger	Bronze 5%tin	CF+S	Cutting	1 hour	Animal carcass
24B	Knife-dagger	Bronze 15% tin	CF+S	Cutting	1 hour	Animal carcass
25B	Axe	Copper	CF+S	Felling	1 hour	Wood
26B	Axe	Bronze 5% tin	CF+S	Felling	1 hour	Wood
27B	Axe	Bronze 15% tin	CF+S	Felling	1 hour	Wood
28B	Knife-dagger	Copper	CF+A+S	Cutting	1 hour	Animal carcass
29B	Knife-dagger	Bronze 5% tin	CF+A+S	Cutting	1 hour	Animal carcass
30B	Knife-dagger	Bronze 17% tin	CF+A+S	Cutting	1 hour	Animal carcass
31B	Axe	Copper	CF+A+S	Felling	2 hours	Wood
32B	Axe	Bronze 5% tin	CF+A+S	Felling	2 hours	Wood
33B	Axe	Bronze 17% tin	CF+A+S	Felling	2 hours	Wood
34B	Knife-dagger	Copper	CF+A+SCF+S	Cutting	1 hour	Animal carcass
35B	Knife-dagger	Bronze 5% tin	CF+A+SCF+S	Cutting	1 hour	Animal carcass
36B	Knife-dagger	Bronze 15% tin	CF+A+SCF+S	Cutting	1 hour	Animal carcass
37B	Axe	Copper	CF+A+SCF+S	Felling	1 hour	Wood
38B	Axe	Bronze 5% tin	CF+A+SCF+S	Felling	1 hour	Wood
39B	Axe	Bronze 17% tin	CF+A+SCF+S	Felling	1 hour	Wood

Table 1: Type and characteristics of the different experiments performed.

After the smelting, a combination of different treatments have been applied to conform the tools, such as cold forging (CF), selective cold forging (SCF) -applied only on the cutting edges- annealing (A) and sharpening (S). Every forging treatment has a time-span of 20 minutes. The employ of these specific combination of treatments along the Prehistoric Iberian Peninsula have been proven by the metallographic study of a wide sample of archaeological metal tools [23, 24]. Metallographic and micro-hardness analyses are being carried out at this time to evaluate the accuracy of the processes applied.

The experimental tools were photographed before and after their use. We employed a Zeiss binocular magnifier (model Leica Wild M3C) to record the different types of wears in every phase of the process of production (forging, smoothing, sharpening, and felling/cutting), from x5 to x60 magnification. Silicon rubber moulds of all the tools have been made before the use and then compared after the working process.

This paper deals exclusively with the results obtained from the experiments carried out on the axes, as the experiments on the daggers are still being performed at the moment. After consulting the rare discoveries of prehistoric hafts and the experiments carried out by others scholars [25, 26], we decided to insert the axes into a socket of a 1 meter long wooden handles of chestnut (*Castanea*). The axes were used 1 or 2 hours to cut wood of various types of hardness: poplar (*Populus*), pine (*Pinus Halepensis*) and tamarind (*Tamarindus Indica*).

RESULTS

Archaeometallurgical results (1)

Elemental analysis was made with a portable XRF-ED spectrometer of the National Archaeological Museum of Madrid – a Metorex XMet 920 with AM241 source and Si-Li detector. The objects were mechanically polished to clean the surface. Calibration is based on the analysis of standards with know elemental compositions. Detection limits vary from each element: 10 ppm (silver and antimony), 100ppm (arsenic, lead, tin, gold, iron) to 200 ppm (nickel) or 1000 ppm for zinc. Micro-hardness test was made with a Remet XH-1000 (300 g load and 15 seconds).

Nº	Tool	Copper %	Tin %	Iron %	H. Vickers
25B	Axe	99,9	0,02	0,07	
26B	Axe	94,2	5,7	0,07	
27B	Axe	85,9	14,0	0,16	
31B	Axe	99,7	0,26	nd	
32B	Axe	94,9	5,0	0,11	
33B	Axe	84,9	14,9	0,18	
37B	Axe	99,9	Nd	0,06	79-104
38B	Axe	95,2	4,7	0,06	97-134
39B	Axe	85,6	14,4	nd	125-189

Table 2: Results of chemical composition and micro-hardness analysis on experimental axes

Traceological results: technological wears

Several difficulties were found during the melting and pouring of the different metals employed. Regarding copper, it was necessary to reach quite an elevated temperature (1050 ºC or more) and the resulting smelted metal had a low viscosity index. For this reason copper axes shows rounded borders with some irregularities. Melting point was considerably lower when tin was added to copper. The smelted metal was very fluid and the cast pieces had well defined borders and cutting edges (plate 1).

There also were problems during post-casting treatment. Copper tools could be easily cold forged. However, they had the worst finished. In turn, bronze tools appeared to be harder and brittle during forging and they some times broke, but their morphology and their edges were better defined.

The above related metallurgical processes produced a series of wears (table 3 and plate 2). The most common are grooves produced during the smoothing and the sharpening, both actions apparently impossible to differentiate. The grooves appear in groups, with homogeneous morphology, parallel to each other and with a variety of directions. They cover the whole surface of the object and they are so numerous as to be impossible to process. Other less frequent patterns than can be produced during the metallurgical processes are notches or small regular depressions placed on the edges. Finally, some manufacture defects can be seen, such as small cracks and prominent borders.

(1) The analytical part of this research was made by Ignacio Montero (CSIC, Madrid).

These serie of patterns does not affect every object to the same extent. While grooves are always very abundant in the whole set of tools, notches and manufacture defects are less numerous and appear chiefly on copper objects, secondly on bronze alloys with a high tin content (15-17%) and never on bronze alloys with a low tin content (5%). Until now, we had not observed any differences that can be produced by the different forging and annealing processes that were employed.

Nº	**Raw material**	**Post-casting treatment**	**Time of work**	**Technological wears**				
				Notches	**Cracks**	**Burr**	**Grooves**	**Total**
25B	Copper	CF+S	1 hour	7	-	1	-	8
26B	Bronze 5% tin	CF+S	1 hour	-	-	-	-	-
27B	Bronze 15% tin	CF+S	1 hour	-	1	-	-	1
31B	Copper	CF+A+S	1 hour	4	1	-	-	5
32B	Bronze 5% tin	CF+A+S	1 hour	-	-	-	-	-
33B	Bronze 17% tin	CF+A+S	1 hour	2	2	-	-	4
37B	Copper	CF+A+SCF+S	1 hour	2	-	-	-	2
38B	Bronze 5% tin	CF+A+SCF+S	1 hour	-	-	-	-	-
39B	Bronze 17% tin	CF+A+SCF+S	1 hour	-	1	-	-	1

Table 3: Type and number of technological wears recorded on experimental axes

Traceological results: use-wears

The use-wear traces we are referring to have a morphology that is similar to the above mentioned patterns, but to identify them is not an easy task (table 4 and plate 3). In fact, use-wear grooves superpose to a field of view which is saturated with technological grooves, and this makes them almost indistinguishable. Only a few grooves have been identified as use-wear grooves; they appear usually isolated or, less frequently, forming small groups. They differ in size and direction from technological grooves, they are perpendicular or slightly oblique to the edge and their size is less homogeneous, in length (from 100 to 20 μ^2) and in width (from 1 to 8 μ). They occur in abundance in copper and 15-17% tin bronze, and are less common in bronze alloys with a low tin content (5%).

Nº	Raw material	Post-casting treatment	Time of work	Use-wears				
				Notches	Cracks	Burr	Grooves	Total
25B	Copper	CF+S	1 hour	3				
26B	Bronze 5% tin	CF+S	1 hour	3	-	5	1	9
27B	Bronze 15% tin	CF+S	1 hour	-	1	1	7	9
31B	Copper	CF+A+S	1 hour	4	1	-	4	9
31B	Copper	CF+A+S	2 hours	2	1	-	4	7
32B	Bronze 5% tin	CF+A+S	1 hour	3	-	4	4	11
32B	Bronze 5% tin	CF+A+S	2 hours	3	-	4	4	11
33B	Bronze 17% tin	CF+A+S	1 hour	6	1	2	7	16
33B	Bronze 17% tin	CF+A+S	2 hours	6	1	2	1	10
37B	Copper	CF+A+SCF+S	1 hour	2	-	3	-	5
38B	Bronze 5% tin	CF+A+SCF+S	1 hour	2	-	2	1	5
39B	Bronze 17% tin	CF+A+SCF+S	1 hour	-	1	-	5	6

Table 4: Type and number of use- wears recorded on experimental axes

Notches are easier to distinguish as they are individualized traces. Regarding to copper and due to its ductility, use-wear notches not only differ from technological ones, but also are able to make them disappear, as it happened in some cases after one hour of work (object 25B) or two hours of work (object 31B). Other technological notches were modified during use, some of them enlarged (objects nº25B and 37B) and some others reduced their size (objects 25B and 31B). There is no size modification in the rest of the objects, but a certain smoothening on the shapes and a bluntness of the edges is generally observed after use.

On bronze tools, the effects of use are diverse. Axes made with a low tin content (5%) did not show any technological trace, only use-wear traces were detected after use. On the contrary, when tin proportion increases (15-17%) there appear notches and cracks during the technological process. They are enlarged or attenuated by use in the same way as copper tools. Nevertheless, there are many use-wear notches in both copper alloy tools (11 cases) and only two of them were attenuated after the second hour of work. The morphology of the notches was most commonly semicircular and irregular. They had various sizes (a length of up to 90µ and a width of 50µ) and most of them were visible to the naked eye. The lateral or distal points of some notches presented an outgrowth at one of their sides, forming ridges.

Burr is another usual use-wear trace. It occurs when the metal that forms the cutting edge raises and bends backwards over one of the sides of the tool. Besides to this, it can also produce an abrupt prominence. It is a characteristic deformation of acute edges, cause by pressure. We have detected only one case of technological burr in the copper axes, however, they appear abundantly after use. Use-wear burr can occur associated or not to notches and cracks. Unlike technological burr, use-wear burr appears with a remarkable frequency in bronze alloys with a low tin content (5%) and they can become even the most abundant use-wear trace in this kind of axes. These small deformations are usually imperceptible to the naked eye, except in rare occasions. Their measures commonly range from 3 to 30µm of length and 1 to 10µm of width, and can exceptionally reach a length of 55µm and a width of 25µm.

Manufacture defects, such as cracks, which have been above mentioned amongst the technological traces, have suffered a transformation after use, getting larger (27B), becoming semicircular notches (33B), developing burrs (33B), or getting smoother (39B).

CONCLUSIONS

In spite of the reduce number of samples, a series of preliminary conclusion can be highlighted at this moment:

The XRF elemental analysis show a commonly known disagreement between the amount of copper and tin melted and the real composition of the axes (losses of tin). Only in one case (nº 26) the amount of tin is higher than expected, probably owing to some residues of previous smelting localized into the crucible. The same explanation can be applied to clarify the existence of tin traces in pure copper axes.

The results of micro-hardness testing validate the greater hardness of the most forged tools. The rank values obtained overlap with the achieved by others scholars on Iberian Peninsula archaeological flat axes [27]. Besides this analysis confirm that cold forging was not so intense, being restricted to the most external area of the axes. More research is needed to assess the effect that time of working has on the hardening of cutting edge, maybe comparable to soft forging.

Regarding use wear traces, the main conclusion that can be drawn from our study is that raw material affect significantly to the development of use-wear traces, mainly in a quantitative way and secondly in a qualitative way. Thus, in spite of their being the same kind of traces, the number and intensity of use-wear traces seem to depend on the hardness and malleability of the raw material. Bronze alloy with a low tin content (5%) seems to be the raw material that has less technological and use-wear deformations from the alloys studied. Its most characteristic response to pressure is the formation of small ridges. Nevertheless, the effect that is exerted by raw material can overlap to those exerted by other variables, such as time of work or even the hardness of worked material, so its evaluation from the archaeological point of view can be difficult to do and needs more experimentation.

Finally, we have not detected any variation that could be due to the combination of several post-casting treatments, such as cold forging and annealing. This fact will allow us to leave this variable out of the next experiments.

ACKNOWLEDGMENTS

We wish to express our gratefulness for the assistance, guidance, discussion and technical support by the following colleagues and friends: Ignacio Montero (CSIC), Salvador Rovira (Museo Arqueológico Nacional), Jorge Chamón, Ana Isabel Pardo, Margarita Arroyo, Maria Reyes, Begoña, Ramón Cadiñanos, Eduardo Kavanagh and Ignacio Martín (Universidad Autónoma de Madrid), Carmen Mensua (Universidad Autónoma de Barcelona), Vicente Lull (Universidad Autónoma de Barcelona), Thilo Rehren (University College of London), Ben Roberts (British Museum), Sue Bridgford (Oxford University), This investigation is supported by the Spanish Ministry of Education and Science (ESTFPU2006-041), Development and Research Department of the Government of Comunidad de Madrid (06/0133/2002) and by the Department of Universities, Research and Information Society of the Catalonia Generalitat (2006BE-2-10059).

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Plate 1. Technological Process

Fig. 1. Untreated copper flat axe.

Fig. 2. Untreated bronze flat axe (5% tin).

Fig. 3. Copper flat axe after forging.

Fig. 4. Bronze flat axe after forging (5% tin).

Fig. 5. Copper flat axe annealed.

Fig. 6. Bronze flat axe annealed (5% tin).

Fig. 7. Copper flat axe after smoothing.

Fig. 8. Bronze flat axe after smoothing (5% tin).

Plate 2. Technological wears

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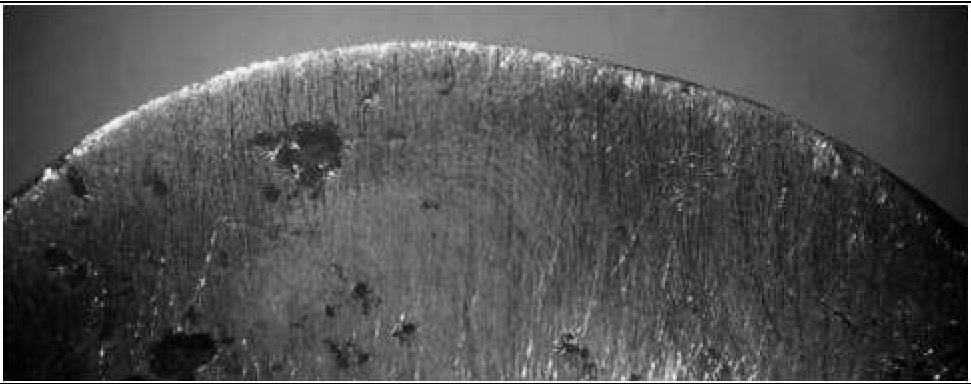
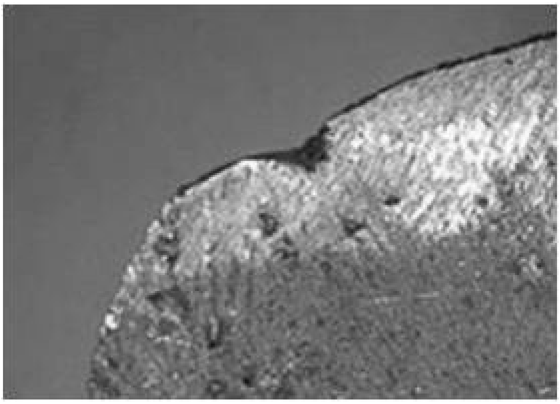
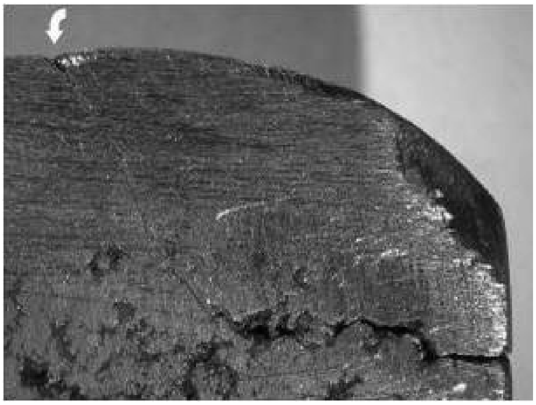
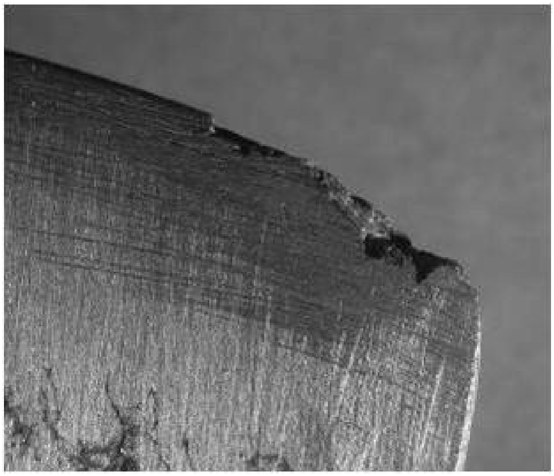
<tr><td colspan="2"></td></tr>
<tr><td colspan="2">Fig. 9. Smoothing grooves on bronze axe cutting edge (17% tin) (6.4x)</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Fig. 10. Groove on copper axe (40x)</td><td>Fig. 11. Groove on bronze axe (10x).</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Fig. 12. Crack on bronze axe (15% tin) (25x)</td><td>Fig. 13. The same crack enlarged after 1 of use, bronze axe (15% tin) (25x).</td></tr>
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Plate 3. Use-wears

Fig. 14. Vertical notch and perpendicular/ oblique grooves, copper axe (25x)

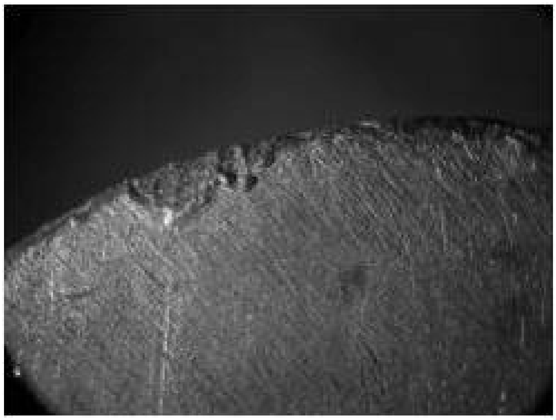

Fig. 15. Burrs on bronze axe (5% tin) (25x)

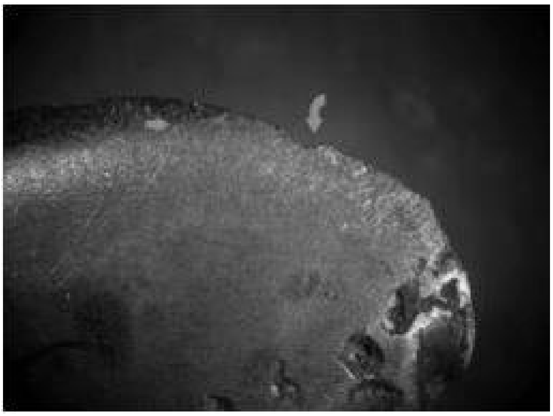

Fig. 16.Perpendicular grooves and notch, copper axe (6.4x)

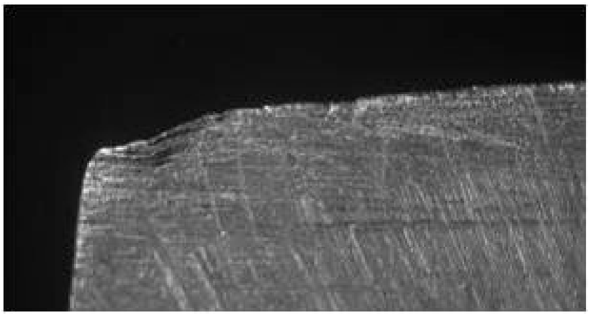

Fig. 17. Notch and burr, bronze axe (15% tin) (25x)

Fig. 18. Technological notches on silicon rubber mould of an axe before use. Technological notches modified after use, bronze axe (17% tin) (10x)