Evidence for indigenous strip-drawing in production of wire at Mapungubwe Hill (1220-1290 AD): towards an interdisciplinary approach

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Abstract:

Several cupreous conical tubes with unclear function are among some of the finds in the collections held at the University of Pretoria which were unearthed by archaeologists on Mapungubwe Hill. Most of these are poorly provenanced, particularly those connected with the activities of Guy Gardner (1935-1940) regarding the waste in northern dump. However, a redetermination of the context following the excavations of the 1970s suggests the funnels date to the period of the rise and development of Mapungubwe as a town and centre of a powerful state. The results from neutron tomography, stereomicroscope and SEM-EDS indicate that the tubes were most probably used in iron strip-drawing to produce wire.

Keywords: Conical tube, Strip-drawing, Neutron tomography, Mapungubwe

1. Introduction

Although several researches were accomplished in regard to technology of metal fabrication in Southern Africa (Becker, 1979; Fouché, 1937; Friede, 1975; Friede and Steel, 1986; Gordon and van der Merwe, 1984; Miller, 1996, 2001, 2002; Oddy, 1991; Steel, 1975) relatively little is yet known about iron fabrication. The lack of sufficient information in this field mostly relates to the corrosive nature of iron. This base metal which is easily corroded when confronted with humidity and oxygen, seldom reaches to a stable state in such environments and usually is found as a bulk of corrosion during archaeological excavations. Such material disintegration is more observable in the case of delicate objects such as wires and strips. The corrosion almost completely destroys the metallurgical evidence of fabrication in them. In these cases finds of remnants of fabrication tools such as a draw-plate are an indicator of the practicing of specific techniques.

Mapungubwe was a later Iron-Age settlement (1220-1290 AD) (Meyer, 1998; Vogel, 1998) located within the Shashe-Limpopo confluence area of southern Africa. The site was successively excavated during the 1930s, 1950s, 1970s and, 1980s and 1990s and considerable amounts of metallic objects were unearthed (Meyer, 1998). The outcomes of archaeological activities beside technical studies of unearthed objects revealed the site was the provenance of a few innovations in metal technology in southern Africa during the Iron Age. One of the earliest appearance of gold, bronze and brass in addition of casting was reported from here (Fouché, 1937; Gardner, 1963; Miller, 2001). Among excavated iron ornaments, delicate iron wires that were mostly fabricated using strip-twisting technique are the prominent identified forms while lack of metallurgical evidence in the form of intense cold working or external feature such as parallel striations due to the corroded nature of rounded wires suggested wire drawing may not have been practiced there (Miller, 2001, 2002). Meanwhile signs of fine corroded wires (1-1.5mm) which were used in decoration of few pendants shaft (Koleini, forthcoming) shows there might be some other technique in fabrication of wires in addition to simple hammering. It is also possible that these wires have been brought into the site along with other imported items in this time such as beads, bronze and brass.

Among excavated items in the Mapungubwe museum collection were several heavily to low corroded small copper funnels whose function was not immediately apparent. It seems cupric conical tube is not an unfamiliar shape in South African metallurgy history albeit the reported item being unique. An almost similar shape was described by Miller (1996) among metal artefacts from the early Iron Age site of Divuyu (550-760 AD) in north-western Botswana. The usage of this funnel artefact has not been determined. The purpose of this study is to reveal the function of the conical tubes from Mapungubwe. Technical study of the funnels by Stereomicroscope, neutron tomography and SEM-EDS showed they were utilized in some kind of iron wire making.

2. Experimental design

2.1. The objects

The archaeological objects investigated consisted of three (Fig.1.a.b.c) copper funnels that were found within the archaeological waste of the earliest excavations (1935-1940) by Gardner at Mapungubwe hill, on the western and northern dumps**.** Although the exact source of these funnels in the chronological sequence of the settlement is not clear it is obvious the funnels should belong to the phases associated with metalworking. Only one of the funnels in the Mapungubwe museum collection is simply provenance by Gardener as having been unearthed 2m below surface. The profile of excavation MK1 which was produced in 1973 in the collapsed north-western wall of Gardner's excavation to reconstruct the site chronology revealed a depth of over 2m. This depth would be synonymous with layer 11 which has been dated to a period from 1243 AD (PTA-1158) to 1252AD (PTA-1159) on the basis of calibrated radiocarbon date (Vogel, 1998). This date is related to the phase three of the settlement ie. the period between 1220 and 1250 AD. The archaeological deposit on the hill only consisted of four phases (Meyer, 1998) while the first appearance of metalworking was reported from phase 2 onwards (Eloff, 1979; Miller, 2001). Phase 1 is associated with a small number of early Iron-Age potsherds, Happy Rest ceramics, which is assumed to be evidence of a small settlement preceded the main occupation of K2 and Mapungubwe. Phase 2 comprises a village settlement identified with K2 (Bambandyanalo) settlement (1030-1220 AD). Bambandyanalo or K2 for short preceded the settlement at Mapungubwe hill, and was located some kilometre away to the south west. The last phase of settlement at K2 coincides with early settlement in the western terrace of Mapungubwe Hill. This soon developed into phase 4 (AD 1220-1250), which is linked with the rise and development of Mapungubwe as a town and the centre of a large state. The final phase 4, is associated with increased settlement on the hilltop and eventual demise of the site.

One of the funnels, MC6, was only covered by a thin layer of cuprite while the other two, MC5 and MC7 were corroded heavily to the extent that their original surfaces as well as their original dimensions were impossible to determine. MC6, which was more or less intact in terms of form, shows the funnel made of a thin plate of copper which has been cut in a conical two dimensional shape. The plate was rolled around its longitudinal axis to from a cone with narrow open sharp vertex. The edges of conical plate formed a tight seam in the joint. The dimensions of the funnels were given in (Table 1).

These conical tubes are larger than the funnel from Divuyu (8.6 mm long) and their manufacture also a little differ from it. As it was described by Miller (1996) the wall thickness of the Divuyu funnel, in comparison with Mapungubwe copper funnels is not uniform and tapered toward the narrow point (Fig.2).

2.2. Instrumentation

The historical evidence present on the surface of the funnels and its mounted cross section were studied by a ZEISS Discovery.V20 stereo microscope (ZEISS SMT, JENA, GERMANY). An AxioCam MRC5 which is a part of device documented the microscopic images.

Neutron tomography was utilized to reveal internal structure of the objects. It was performed at the South African radiography and tomography (SANRAD) facility, which is located at the beam port-2 of the SAFARI-1 nuclear research reactor based at Necsa, near Pretoria. In this port, a 93% thermal neutron beam is produced and utilized for tomography. A full description of the facility can be found in de Beer (2005). The individual tomography slices were visualized and analysed through IMAGEJ software which is available on the (http://www.ansci.wisc.edu/equine/parrihs/imagejpc.zip).

Identifying the composition of the corroded metals and revealing more details with regards to internal structure were achieved by using a Jeol 5800 Scanning Electron Microscope with a Thermo scientific Energy Dispersive X-ray fluorescence micro-analysis system (SEM-EDS) at Microscopy and Microanalysis Facility at the University of Pretoria. The analysis was directly performed on the mounted sample.

For analysing the composition of material constituents of funnel a 3 mm^3 of the MC7 from its tapered part was cut off transversally by jeweller's saw. The samples were embedded in resin and grinding with silicon carbide paper up to grade 800 then polishing with diamond paste up to grade 0.25 micron with ethanol base lubricant. To prevent the electrical charge the samples were coated with a thin layer of carbon.

3. Results and discussion

The neutron tomography revealed the funnels MC5 and MC7 corroded heavily with almost no metal core. In the most parts metal was converted to dense corrosion products which have kept the original form of the objects in such a way that the interior fine details are clearly obvious. The successive axial slices of MC5 (Fig.3a-d) show a thin hollow wire (pipe) on the core. The diameter of the wire was gradually decreased toward the narrow point of the funnel while the unclosed seam converted to a closed joint. No sign of conjunction between the funnel wall and the tube is observable. Physical evidence on the wide side of the funnel (Fig.3a) shows the wire was longer and extended outwards. It seems corrosion completely destroyed the external part. Contrasting of the tube and the funnel wall in slices indicates both have the same linear attenuation coefficient (μ - values) property for neutrons therefore a probable same composition.

In MC7 dissolution of metal in environment formed a longitudinal void in the funnel wall. Nevertheless the main form and the interior structure have remained intact among the corrosion products (Fig.4a). Signs of a bow strip adjacent to the funnel wall with its higher attenuation coefficient compare to main material constituent of the funnel (copper) is recognizable in white from almost the middle (Fig.4b). From this point successive axial slices show with diminishing the diameter of the funnel the strip has folded as becomes narrower (Fig.4c-f). The folds are observable in the form of a cellular structure around a central hole or tube among the funnel in axial and frontal slices respectively (Fig.4a.e.f). The high contrast between the strip and funnel wall is mainly due to the discrepancy of material constituent of two structures with different mass absorption properties (μ -values) which neutron beam is sensitive to. Consequently the strip must have different composition.

Tomography revealed MC6 has a same interior structure as MC7. A strip with different composition is seen completely across the funnel which gradually folds toward the funnel narrow point to form a solid wire (Fig.5a-d). Here also the composition of the strip differs from the funnel wall and is seen in white in axial slices.

Among these funnels, MC7 was the only one which has study value where removing the representative sample could be performed without disintegrating the whole object. The cross section of the narrow point of the funnel is seen in (Fig.6). Three main zones are observable in this image. Zone (a) consists of folded wire, central tube and peripheral holes around it which were filled by corrosion products and soil contaminants. Colour of material constituent of this zone (red to reddish brown) is noticeably dissimilar to the other zone (different hue of green and purple) which indicates its composition must be quite different. Zone (b) belongs to copper plate which corroded completely. Zone (c) mostly consists of green copper corrosion products which have coated on the surface of the funnel wall. The thickness of copper plate in areas that increase the volume of corrosion products has not affected its dimensions, which are about 0.4-0.5 mm. This thickness is quite similar to MC6 and shows the funnels were made of with almost the same thickness of copper plate. The thickness of strip among the funnel after corrosion is quite lower than the funnel wall (<1/2 thickness of copper plate) although the corroded structure of the strip could not reveal the exact thickness of the strip before corrosion. The wire diameter in this place which is almost close to the vertex of the funnel is about 3mm.

A summery of EDS compositional analyses of material constituent of different zones along with a BSI image showing the position of the electron probe micro analyser on the surface of mounted sample were presented in (Fig.7). Position (1) concerns the martial constituents of central hallow among the folded strip leading to the EDS spectra of MC7(a1) revealing high amount of calcium probably in the form of calcium carbonate ($CaCO_3$) and low amounts of Mg, S and K originating from burial context, as well as corrosion products of iron and copper. Position (2) corresponds to the folded strip giving rise to the EDS spectra of MC7(a2) exposing iron and oxygen as the main constituents which means the strip was made of iron. The EDS spectra developing from position (3) where the strip lies adjacent to the funnel wall revealed admixture of iron and copper corrosion products in association with soil elements (Al, Si, S and Ca) which is a typical result in corroded multi-metal structure. Position (4) refers to the funnel wall resulting in the EDS spectra of MC7(b4) showing Cu and O as the prominent elements in composition which indicated the funnel was made of unalloyed copper.

It seems the funnels were used as die for drawing strip of iron and copper to produce fine wires. Strip-drawing which is known as Egyptian wire-making method was explained thoroughly by Williams (1924) in regard to silver and gold. In this technique such as conventional wire-drawing decreasing the diameter of the wire, needs passing through tapered holes with gradual diminishing size. Although the corroded structure of the funnels from Mapungubwe made it hard to determine the exact interior diameter of their tapered points direct observation of exterior form of funnels indicates the holes have different sizes (Fig.1). The folded structure of the wires around a central tube among the funnels (MC6 and MC7) refers to the first pass of the iron strip. Williams (1924) in regard to this stage suggested that after the first pass the strip converts to a tube with some distortion in metal structure while subsequent passes from smaller holes steadily amended these deformations as diminishing the central hollow. Strip-drawing, contrary to wire-drawing, exerts very little strain on drawing die consequently dies of softer material such as copper may be practical in forming the harder one for instance iron although receiving to a precise idea in this regard needs testing the technique with the same materials and equipments practically. Structure of hollow wire among MC5 was quite different and no sign of folding was observable. It is possible the width of the strip in relative to the other strips and compare to the funnel hole was lower then lesser pressure inward to it during passing through it. Since there was not any conjunction between the tube and the funnel this stage was not the first pass of the strip. Superficial microscopic deep scratch marks on the surface of MC6 (Fig.8) could be evidence of usage of the funnel in the process of strip-drawing. These scratches are seen in the form of close irregular lines which were extended towards one direction along the funnel length. These marks presumably formed during movement of the funnel as it was clamped within/on a soft immoveable base such as a wooden base. The presence of unfinished fabricated wire among the funnels indicates failure during the process of strip-drawing for instance by breaking the wire close to the exit point. In this condition the funnel was discarded.

It is likely the thin delicate iron wires that were used in decorating of the shaft of two pendants from Mapungubwe and its Southern Terrace fabricated by this method. These pendants that their structure was discussed thoroughly in Koleini (forthcoming) corroded heavily as the twisted wire around the shaft is only obvious in Neutron tomograms. The thickness of the corroded wires (1-1.5 mm) was such, that it was not possible to form them on the basis of simple forging, while lack of sufficient metallurgical evidence prevents a precise decision on their fabrication method. Up to now no metalworking evidence has indicated such wires were manufactured on the site. Consider that the trading with overseas merchants was one of the economical activities of the settlers (Huffman, 1972, 2000) there is also this possibility that the wires or the pendants were among the imported items brought into the site. The pendants were discovered in MK1 layer11 and in K8 l(iii) which were dated 1243-1252 AD and 1284 AD respectively (Vogel, 1998). The coincidence of the date of the funnels appearance and the thin wires in phase three of the settlement, makes this a probability that strip-drawing might be the method utilized in the fabrication of the wires.

4. Conclusion

The evidence provided in this study is relevant to the function of the funnels in metalworking experience of Mapungubwe inhabitants during the Iron Age. By means of utilizing instruments such as stereomicroscope, neutron tomography and SEM-EDS analysing system it was revealed these simple ordinary conical tubes were used to fabricate delicate wires by drawing a thin strip of iron or copper through them. This indicates that the Mapungubwe inhabitants during the phase 4 settlement were familiar with the strip-drawing technique and its usage in the fabrication of wire. This was an innovation in wire making that could be the earliest practice of its kind in southern Africa on the basis of existing metalwork evidence. The results also illustrate the efficacy of neutron tomography in revealing the internal structure of funnels non-destructively.

2.3. Acknowledgments

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Table 1
Objects physical characteristics

Objects	Weight (*g*)	Diameters *(mm)*	Length *(mm)*	Wall thickness *(mm)*
MC5	2.6	4.42- 7.94	33.00	1.93
MC6	1.9	2.84-6.49	28.56	0.64
MC7	3	5.15- 9.20	32.46	1.59

Figure 1: Three funnels from Mapungubwe museum collection; *a* MC5, *b* MC6 and *c* MC7.

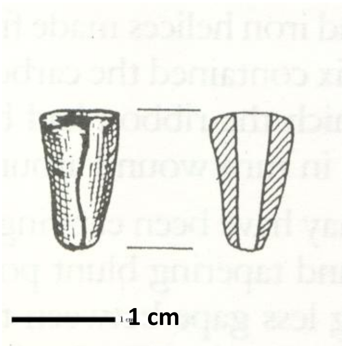


Figure 2: Conical tube from the Early Iron Age site of Divuyu (Adapted from Miller 1996).

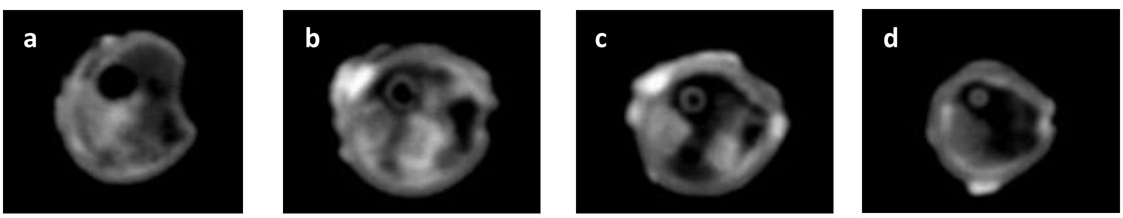


Figure 3. Neutron tomograms of MC5. Successive axial slices. *a* The axial slice shows the wide end of the funnel close to exterior. A round hallow is seen exactly in the same place that wire starts to appear in following axial slices. *b,c,d* Presence of a narrow tube among funnel is observable. Diameter of the wire gradually decreases toward the narrow point of funnel.

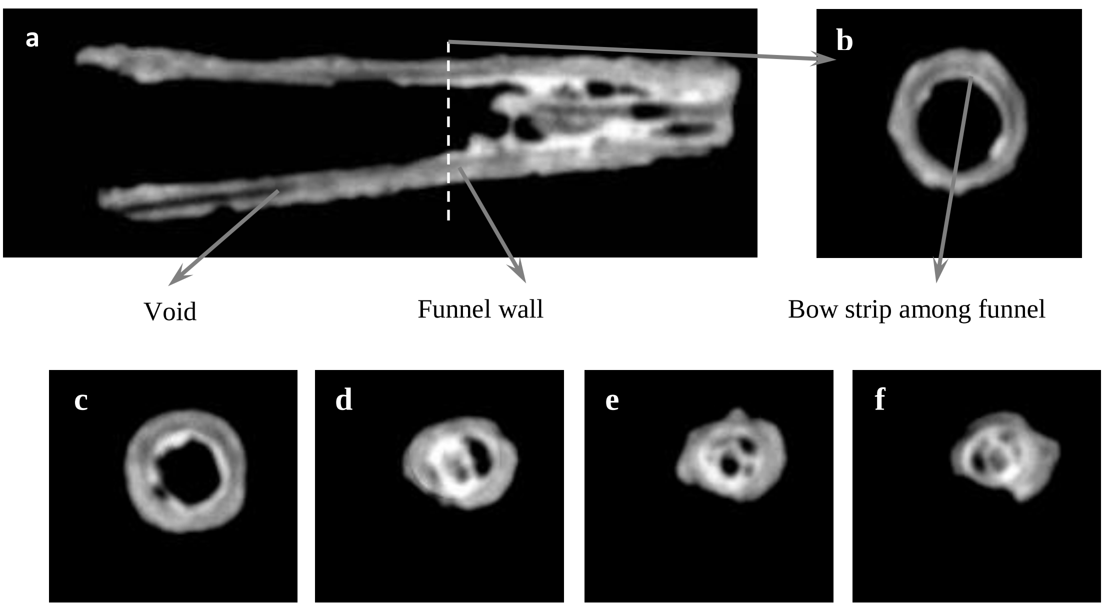


Figure 4. Neutron tomograms of MC7. *a* Frontal slice shows almost the middle part of the funnel. Folded strip is seen in the form of longitudinal cellular structure in white and light grey among funnel while the central hollow is in dark grey and black. *b,c,d,e,f,*) Axial slices show the gradual folding the strip along funnel interior (in white).

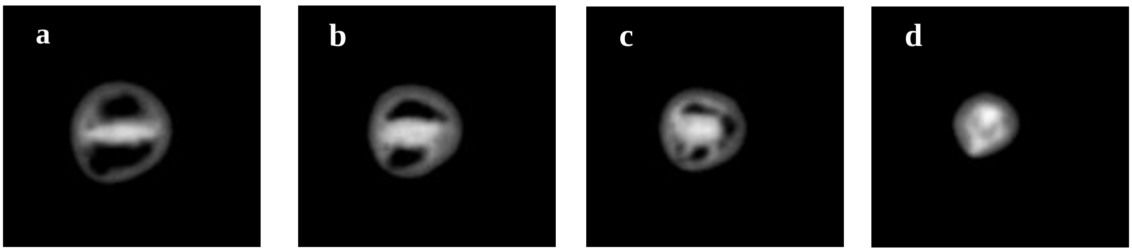


Figure 5. Neutron tomograms of MC6. *a,b,c,d* Successive axial slices. In white: strip. The funnel wall is in grey.

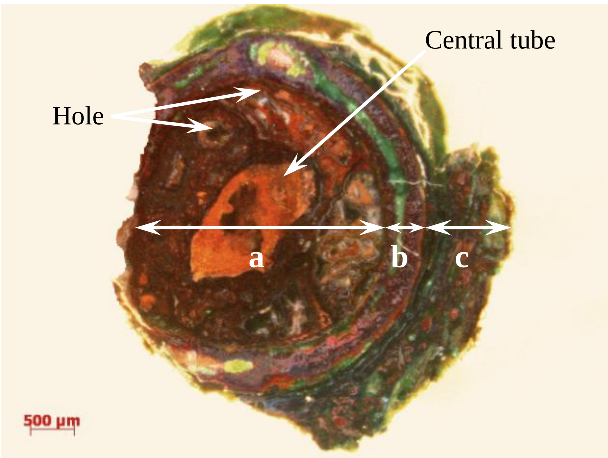
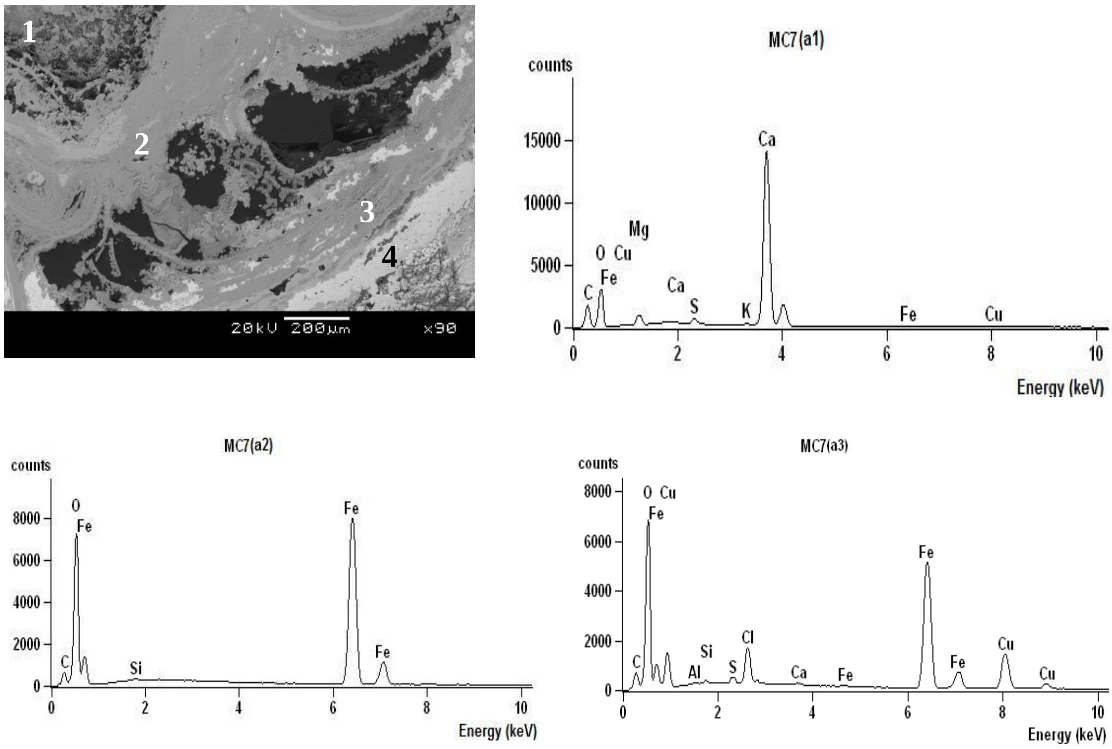


Figure 6: Microstructure of transverse section in narrow point of MC7. Zone *a*: folded strip among funnel. Zone *b*: funnel wall. Zone *c*: corrosion products on exterior surface of funnel.



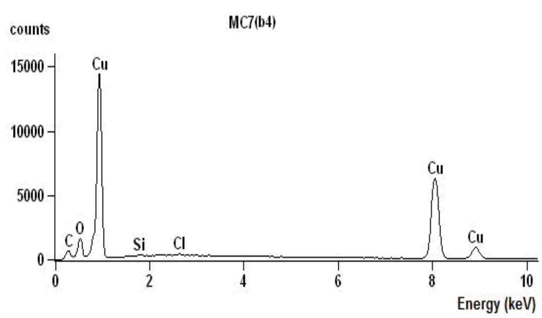


Figure 7: Left above SEM (BSE) micrograph of MC7 interior structure showing positions of EDS analyses on the mounted cross section. EDS analyses: MC7 (a1) interior hollow among strip, (a2) folded strip, (a3) folded strip next to cupreous funnel wall, (b4) funnel wall.

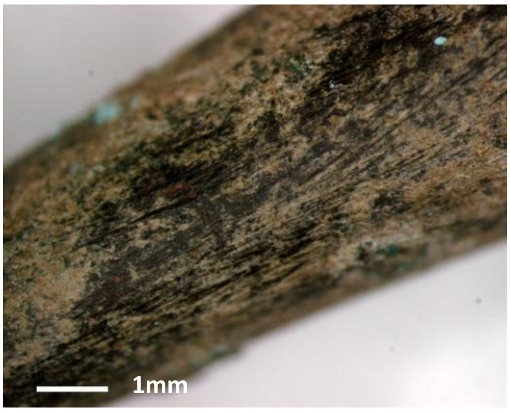


Figure 8. Micrograph of abrasion lines on the surface of funnel shape copper object (MC6).