

THE ROLE OF METALLOGRAPHY IN THE RESTORATION OF AN INCENSE BURNER FROM PERSIA

TAMÁS BUBONYI¹ – SZILVIA GYÖNGYÖSI² – LEA NAGY³ –
PÉTER BARKÓCZY⁴ – ESZTER BAKONYI⁵

Abstract: Before the restoration of a metallic object, detailed analysis of the metal and the microstructure could provide useful information about the techniques used for producing it. Additionally, it is possible to obtain data about the metal and the object, which expands the knowledge about the origin of the object and its raw material. This study introduces this field through the metallographic analysis of an incense burner from Persia, from the Quajar period of the 19th Century Iran. The results of the metallographic investigation are not only used for the restoration work but also for archaeometry and archeology. The burner was made from a heterogeneous brass alloy. The antecedents of the burner were unknown so local heating was applied to avoid the brittle breakages. Selenium content was detected in the sulfide inclusions which shows a Near-East origin of the raw material.

Keywords: metallography, restoration, chemical analysis, selenium, brass

INTRODUCTION

An incense burner from Persia was examined (*Figure 1*). This burner is owned by the Ferenc Hopp Museum of Asian Arts and is exhibited in Budapest. The burner was damaged, the body was broken, and some small part were missing. Lea Nagy made the repair and restoration of the burner [1]. Due to the large extent of deformation, it was an important question if the raw material was brittle or ductile. This basic property of the metal determines the best practices during the manufacturing process [2]. Additionally, it was necessary to complement the missing part. Chemical analysis was needed to choose the best alloy for the restoration [3, 16, 17]. However,

¹ Department of Physical Metallurgy, Metalforming and Nanotechnology, University of Miskolc
H-3515 Miskolc-Egyetemváros, Hungary
fembubo@uni-miskolc.hu

² Department of Solid State Physics, University of Debrecen
H-4026 Debrecen, Bem Square 18, Hungary
szilvia.gyongysi@science.unideb.hu

³ University of Fine Arts
H-1062 Budapest, Andrásy str. 69–71, Hungary
nagy.lea@gmail.com

⁴ Department of Physical Metallurgy, Metalforming and Nanotechnology, University of Miskolc
H-3515 Miskolc-Egyetemváros, Hungary
fembarki@uni-miskolc.hu

⁵ Hungarian National Museum
H-1088 Budapest, Múzeum krt. 14–16, Hungary
bakonyi.eszter@gmail.com

the chemical composition by itself was not enough to make the suitable replacement. To determine the original production method was also necessary to approximate the original status and outlook after the repair [4, 11]. Therefore, a full metallographic description was necessary before the restoration and repair could begin [5, 13, 18].

The basic steps of the production can be identified by the status of the microstructure [6]. These steps are casting, plastic deformation and heat treatment [7]. Based on the alloy and the microstructure, basics of the production technology can be reverse engineered [8, 19]. A detailed quantitative description of the microstructure gives a chance for a more detailed analysis and description of the circumstances of the processing. Optical microscopy is the best investigation method for the microstructure, and additional SEM-EDS analysis helps to identify the different phases or precipitations based on their local composition. Sometimes the surface condition, possible layer is also important. In these cases, the SEM-EDS study also helps [9, 14, 15].

Metallographic analysis belongs to the destructive material testing methods [10]. Taking sample from the objects is necessary. This is not a problem before the restoration, however, the size of the samples in case of artifacts is small in almost every case, so it is important for the sample to represent the whole artifact [11]. In the case of the burner the damaged part has a grained lace like fine structure, so the relevant sample is consequently very tiny. To see the importance of the questions, a detailed analysis and description was performed, and the results are summarized in this article.

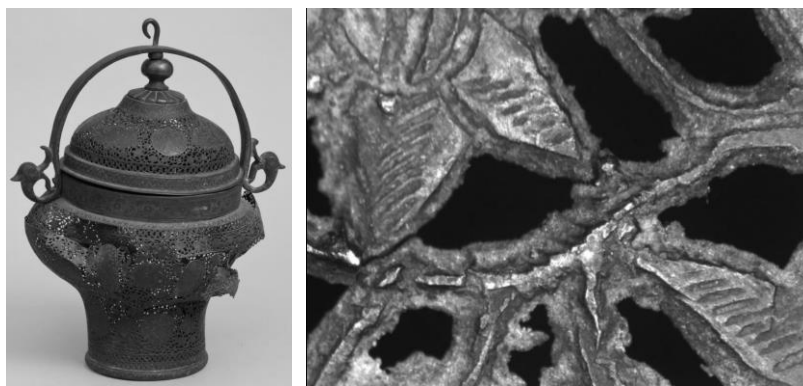


Figure 1

The examined incense burner and the lace like broken part in larger magnification

1. MATERIALS AND METHODS

A sample was cut from the lace like parts, and the cross-section of the sample was examined. The preliminary SEM-EDS analysis shows that the raw material of the burner is brass. Therefore, the sample was grinded and polished mechanically. The polishing was performed with 3 and 1 μm diamond particles. Immersion etching was applied using FeCl_3 solution. The microstructure was observed with a Zeiss AxioImager M1m microscope. The SEM-EDS analysis was made by Árpád Kovács at LISA

Strategic Research Infrastructure of the Faculty of Materials Engineering, University of Miskolc. A Zeiss EVO MA 10 SEM was used with an EDAX EDS system.

2. RESULTS AND DISCUSSION

As visible on *Figure 1*, the lace-like part of the burner is broken. The larger magnification shows the fine structure of this lace-like part. Elements with small cross sections hold the top of the burner. The picture suggests that this is a carved and inwrought part. A small piece of the material was removed and analysed with SEM-EDS. *Figure 2* shows the micrograph of this part.

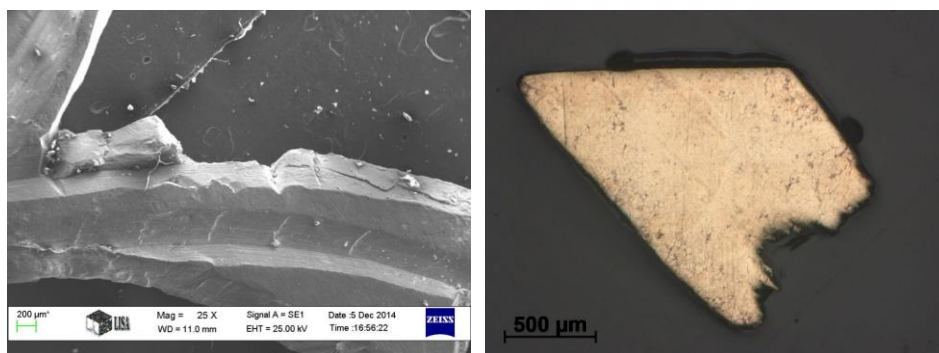


Figure 2

SEM micrograph taken from the examined part of the burner (left) and the prepared cross section of this sample (right)

The SEM micrograph of *Figure 2* clearly reveals the traces of carving, so this is the necessary technique of production and ornamenting the extensions. The surface of the sample was analysed. The analysis shows that the sample is brass with 30 w% zinc content. Additionally, 1 w% silver and extremely high 8 w% lead content was measured. Consequently, in the following tests, the sample was handled as brass. The lead content on the other hand was too high, so the cross section must be analysed as well to compare with the surface for identifying the extent of the corrosion. The corrosion process causes the segregation of lead to the surface of the metal.

The SEM –EDS analysis of the cross section of the sample shows 35.5 w% zinc content and 0.5–1 w% lead content. Silver was not detected in the bulk. This large difference of the lead content at the surface and the bulk shows a strong corrosion, which was not trivial at the first observation of the burner. As a result, the cleaning of the surface was necessary during the restoration. The zinc content suggests inhomogeneous brass which can be seen on *Figure 3*. The β islands and pins exist in an α matrix. The pins of β draw the dendritic structure of the raw material. This suggests a cast raw material. On the microstructure of *Figure 2*, the heterogeneous structure, where the top and the bottom of the sample contains more β than the central area of the cross section, can clearly be seen. This shows that a thin plate was cast, and this

plate was then manufactured. The large cooling rate caused the segregation at the surface area. This is supported by the dendritic-like structure as well. The differential interference contrast (DIC) micrographs of the sample (*Figure 4*) reveal the twin boundaries and small grains, which are typical after the recrystallization process. These can be observed mainly near the surface. The carving creates plastic deformation, and the microstructure shows that the material was heat-treated, annealed after carving. The fast cooling can produce brittle brass due to the β - β' transformation, and annealing can increase the ductility of the material.

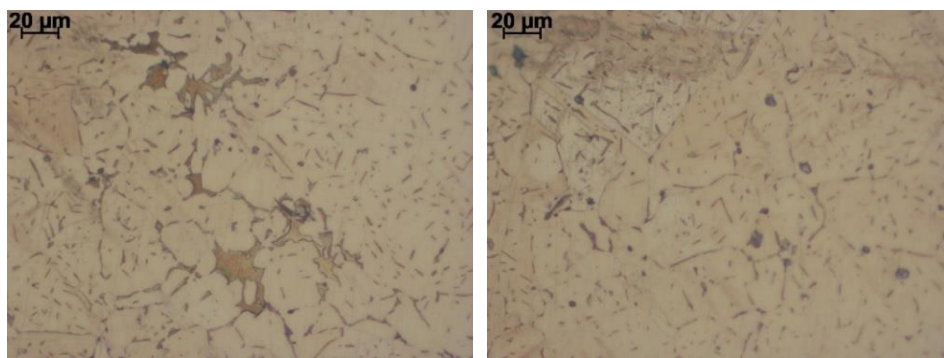


Figure 3
Optical micrographs from the microstructure of the burner

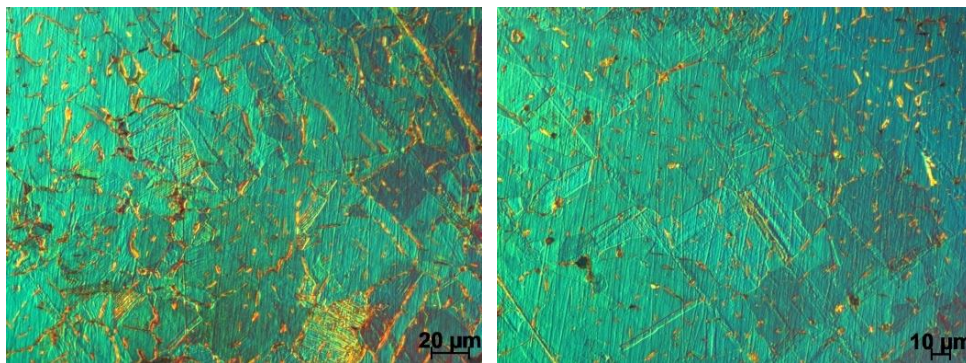


Figure 4
The microstructure of the examined sample illuminated and analysed by DIC technique

Next to the β , other phases-inclusions were revealed by the optical microscopic observation. Therefore, a detailed SEM-EDS analysis was performed. *Figure 5* shows the SEM micrographs, where the different analysed phases are marked with numbers. The left image shows the typical appearance of α (1) and β (2) phases. The α phase contains 35 w/w% zinc while the β contains 45.3 w/w% zinc. The right image

also shows the α (1) and the β (3, 4) phases with the same composition. It is interesting that the microstructure contains pure copper (2, 5) which shows that the alloying of the raw material was not properly performed. Comparing the above information with the plausible manufacturing method, it is possible that the alloy was produced only for this object.

On the left micrographs of *Figure 5*, number 3 denotes the lead inclusion. It is white in the SEM micrographs due to the larger atomic weight related to the surrounding. These inclusions appear to be pure lead, the copper cannot solve the lead either in liquid or solid state. Therefore, the lead forms smaller or larger drops during solidification, and solidifies in this form at the beginning of the cooling of the melt. *Figure 6* shows this in larger magnification, and the analysed drops are denoted by 1. Number 2 denotes phases in both micrographs, where the local chemical analysis detected a high content of selenium.

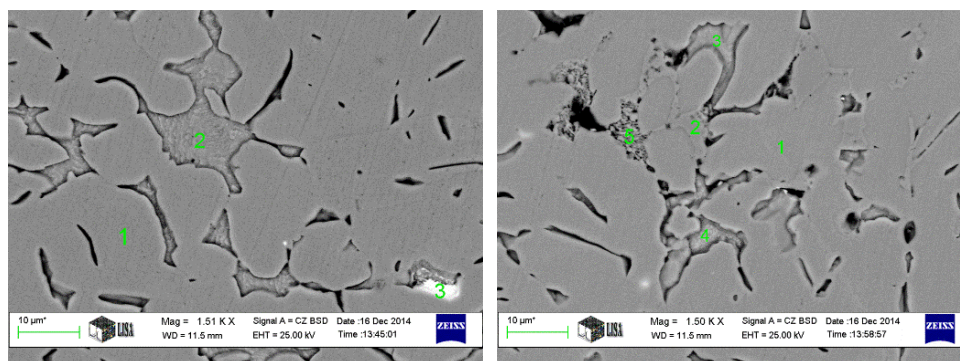


Figure 5

Different kinds of phases and the positions of the local chemical analysis in the microstructure of the sample from the burner

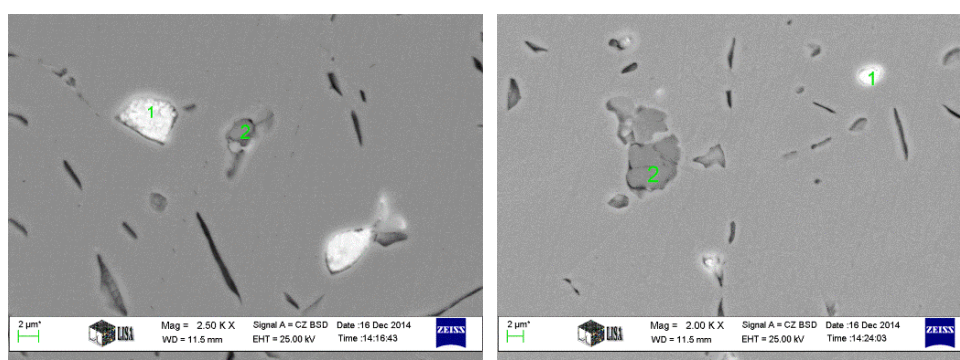


Figure 6

Positions of the local chemical analysis of selenium containing inclusions, and their morphology

These phases are basically copper-sulphide inclusions from the smelting process. Additionally, beside the sulphur these contain 9 w/w% selenium too. The sulphur and the selenium are chemically compatible and can substitute each other in the same chemical reactions. So, the sulphide copper ores can contain selenium, and the smelting process will be the same.

The copper-selenides are rare; therefore, they can be used as a trace of the origin of the ore. One typical place where selenides can be found is the Near-East, the estimated origin of the burner. Due to the large fossil deposition (oil basin) the selenium content of the copper ores can increase. This phenomenon and the inclusions show the origin of the burner next to the typology, the ornaments and the documentation.

The metallography of a small part of the burner revealed that the raw material of the burner is heterogeneous brass with some small-sized lead and sulfide inclusions. The possible manufacturing of the damaged lace-like part is: 1. casting a plate, 2. preparing the carved and inwrought pattern, 3. heat-treatment. The alloy could be brittle based on the chemical composition and the possible manufacturing method. A short-term local heat treatment was applied (~450 °C) before the bending of the material in the damaged parts. The extensions were made from common brass (C26000). The chemical composition of wire brass (C27000) is closer to the burner, although it has a higher tensile strength, and acts like a spring. The cold-rolled state was used for carving. First soldering was planned to fix the parts in the damaged area, but the structure was too fine for a successful application. Finally, sticking was used. Special high strength glue was applied due to the possible remaining elastic stresses.

CONCLUSIONS

An incense burner originated in Iran was examined before the restoration work. The burner was broken, and some parts were missing, so a large repair and substitution work was necessary. For this work the analysis of the chemical composition was necessary. The bulk material is brass (35.5 w% Zn and 0.5–1% lead). The material was cast to a plate, then ornamented by carving. After the carving the burner was annealed. The basic question of the repairing was the ductility of the raw material. This is a heterogeneous brass material, which can be brittle, especially if the estimated manufacturing method is taken into consideration. So, the local heating of the bent parts was suggested. Additionally, the lead content was extremely large at the surface, which indicates an intensive corrosion of the burner, so the cleaning was also suggested. During the metallographic analysis, copper-sulfide inclusions were found which have large selenium content. These inclusions are from the smelting process and were used as trace to point to the Near-East as the origin of the raw material. Based on this information the whole repair was made, and the object can be exhibited.

ACKNOWLEDGEMENT

The described article was carried out as part of the EFOP-3.6.1-16-2016-00011 *Younger and Renewing University – Innovative Knowledge City – institutional development of the University of Miskolc aiming at intelligent specialisation* project implemented in the framework of the Szechenyi 2020 program. The realization of this project is supported by the European Union, co-financed by the European Social Fund.

REFERENCES

- [1] Nagy L. (2017). *Perzsa sárgaréz füstölőedény restaurálása*. Thesis, Budapest, University of Fine Arts.
- [2] Hosford, W. F., Caddell, R. M. (2011). *Metal Forming, Mechanics and Metallurgy*. Cambridge University Press.
- [3] Lutz, J., Pernicka, E. (1996). Energy dispersive X-ray analysis of ancient copper alloys: empirical values for precision and accuracy. *Archaeometry*, 38, pp. 313–323.
- [4] Kienlin T. L. (2013). Copper and Bronze: Bronze Age Metalworking in Context. In: Fokkens, H., Harding, A. (eds.). *The Oxford Handbook of the European Bronze Age*. Oxford, Handbooks in Archaeology.
- [5] Scott D. A. (1991). *Metallography and Microstructure of Ancient and Historic Metals*. Tien Wah Press Ltd., Singapore.
- [6] Konečná, R., Fintová, S. (2012). Copper and Copper Alloys: Casting, Classification and Characteristic Microstructures, *Copper Alloys. Early Applications and Current Performance – Enhancing Processes*, Collini, L. (ed.), InTech, ISBN: 978-953-51-0160-4.
- [7] Porter, D. A., Easterling, K. E., Sherif, M. Y. A. (2009). *Phase Transformations in Metals and Alloys*. Boca Raton, FL, CRC Press.
- [8] Fadhil, A. A., Ghattas, M. S., Iskander, B. A., Ajeel, S. A., Enab, T. A. (2018). Structural characterization and detecting processes of defects in leaded brass alloy used for gas valves production. *Alexandria Engineering Journal*, Vol. 57, pp. 1301–1311.
- [9] Cvikel, D., Cohen, M., Inberg, A., Klein, S., Iddan, N., Ashkenazi, D. (2017). Metallurgical characterization of brass sheet from the 19th-century Akko Tower Wreck (Israel). *Materials Characterization*, Volume 131, pp. 175–187.
- [10] Vander Voort (g. F. (2004). *ASM Handbook 9: Metallography and Microstructures*. ASM International, printed in the USA.
- [11] Czichos, H., Saito, T., Smith, L. (eds) (2011). *Handbook of metrology and testing*. Springer-Verlag, Berlin–Heidelberg.

- [12] Dillmann, P., Béranger, G., Piccardo, P., Matthiesen, H. (eds.) (2007). *Corrosion of metallic heritage artefacts Investigation, conservation and prediction for long-term behaviour*. Cambridge, Woodhead Publishing Limited.
- [13] Pollini, J., Giumlia-Mair, A. (2019). The statue of Germanicus from Amelia: New discoveries. *American Journal of Archaeology*, Vol. 123, No. 4, pp. 673–686.
- [14] Dillmann, P., Watkinson, D., Angelini, E., Adriaens, A. (eds.) (2013). *Corrosion and conservation of cultural heritage metallic artefacts*. Cambridge, Woodhead Publishing Limited.
- [15] Mcneil, M. B., Little, B. J. (1992). Corrosion mechanisms for copper and silver objects in near-surface environments. *Journal of the American Institute for Conservation*, Vol. 31/3., pp. 355–366.
- [16] Artioli, G. (ed.) (2010). *Scientific methods and cultural heritage: An introduction to the application of materials science to archaeometry and conservation science*. Oxford University Press.
- [17] Varella, E. A. (ed.) (2013). *Conservation Science for the Cultural Heritage, Applications of Instrumental Analysis*. Springer-Verlag, Berlin–Heidelberg.
- [18] Giumlia-Mair, A., Mráv, Zs. (2014). The aes Corinthium vessels from Egyed, Hungary. *Folia Archaeologica*, LVI.
- [19] Benkő, E., Barkóczy, P. (2017). The archaeology of books. Medieval book clasps and other book fittings from Pilis Cistercian Monastery. In: Benkő, E., Kovács, Gy., Krisztina, O. (ed.). *Crafts and workshops in Hungary During the Middle Ages and the early modern period*. Budapest, Hungarian Academy of Sciences.