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Computer modeling for the visualization and geometric reconstruction of artefacts from the casting workshop in Grzybiany

Modelowanie komputerowe do wizualizacji oraz rekonstrukcja geometryczna zabytków z pracowni odlewniczej Grzybiany

Abstract

The casting workshop in Grzybiany is one of the most important archaeological sites in regards to casting technology from the Bronze and Early Iron Ages. During the "Grzybiany. Osada nadjeziorna z epoki brązu i żelaza" [Grzybiany. Lakeside settlement from the Bronze and Early Iron Ages] research, the structure of casting moulds was analyzed as well as the chemical composition and microstructure of one of the more-interesting metal artefacts found within the workshop. Based on this, geometric visualization was performed with the help of computer-modeling methods. For scientific, experimental, and educational purposes, reconstruction of a zoomorphic pendant was performed using the lost-wax method. Wax models injected into a matrix were used, along with fired ceramic (gypsum) moulds and a specially prepared modeling alloy that corresponds to the original material. In this way, a true replica of the original was obtained: technologically, structurally and chemically.

Studies of production technology of the casting workshop dated back to the Bronze and Early Iron Age help to increase the knowledge of the mould-preparing technology and the alloys used. Modern tools and computer programs aid in the research of old technologies and help disseminate the results.

Keywords: archaeometallurgy, casting, lost-wax method, bronze, computer modelling, 3D visualization

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Streszczenie
Pracownia odlewnicza w Grzybianach należy do jednego z najważniejszych stanowisk archeologicznych pod względem studiów nad technologią odlewniczą w epoce brązu i wczesnej epoce żelaza. W toku prac wykonano analizę struktury form odlewniczych. Przeprowadzono także analizę składu chemicznego i mikrostruktury jednego z ciekawszych zabytków metalowych, odkrytych na terenie pracowni. Na tej podstawie, z wykorzystaniem metod modelowania komputerowego, wykonano wizualizację geometryczną. W celach naukowych, doświadczalnych i edukacyjnych wykonano rekonstrukcję zawieszki zoomorficznej przy wykorzystaniu metody wytapianych modeli. Zastosowano modele woskowe wtryskiwane do matrycy, formy ceramiczne (gipsowe) wypalane oraz specjalnie przygotowany stop modelowy, odpowiadający oryginalnemu. W ten sposób uzyskano wierną technologicznie, strukturalnie i chemicznie replikę zabytku.

Badania technologii produkcji warsztatu odlewniczego z epoki brązu i wczesnej epoki żelaza przyczyniają się do wzrostu świadomości o stosowanych technikach przygotowania form i wykorzystywanych stopach. Współczesne narzędzia i techniki komputerowe wspomagają badania dawnych technologii i służą ich upowszechnianiu.

Słowa kluczowe: archeometalurgia, odlewnictwo, metoda wytapianych modeli, brąz, modelowanie komputerowe, wizualizacje 3D

1. Introduction

Archaeological research in the area of a late Bronze – early Iron Age settlement in Grzybiany (in the Legnica district of Poland) belongs to the most important discoveries in Lower Silesia [1–5]. It is an important element of research of the development of casting techniques, because of the number and technological character of the artefacts. The settlement area, located on the headland extending into Koskowickie Lake, was first excavated during the years 1959–1962 [5]. The research was renewed by the *Institute of History of Material* Culture of the Polish Academy of Sciences in Warsaw, and was conducted over the next seven seasons (1970–1973, 1977–1980) under the direction of Zbigniew Bukowski [3].

Clay casting moulds, the first objects testifying to the manufacturing character of the settlement, were discovered in its central part. Next, a significant concentration of casting workshop remnants that operated here were recognized: castings ladles, tuyeres, metal artefact fragments, casting moulds, and formations testifying to conducting fire processes (roasted clay, hearth remnants). Based on the analysis of mobile artefacts and special analysis, the collection of finds from the workshop area, has been dated to the 6^{th}–5^{th} century BC [1].

Since 2013, these artefacts have been researched by the Copper Museum in Legnica, the Archaeology Institute of Wroclaw University and the Faculty of Foundry Engineering of AGH - University of Science and Technology in Krakow.

The collection of artefacts from Grzybiany was analyzed in detail due to their connection with casting technology. The artefacts researched are considered to belong to a mould preparation and lost-wax casting workshop [6–10]. The moulds from Grzybiany

are disposable, as they were made from a mixture of sand (with differing grain sizes) and clay (Figs 1–4). A mould was prepared by covering a wax model with clay or stamping previously prepared and fired clay models in moist clay.

Fig. 1. Part of casting mould (accession no. 44/77)

Fig. 2. Part of casting mould (accession no. 87/77)

Fig. 3. Macroscopic picture of mould (accession no. 64/78) different sizes of sand grains visible, magnification 7×

Fig. 4. Macroscopic picture of mould (accession no 64/78) different sizes of sand grains visible, magnification 50×

In the workshop area, metal objects and their fragments were also discovered, and their condition suggests that they were damaged as early as in their production stages. By applying proper computer tools, they can be reconstructed so to be conducive to a more-complete analysis of the process. Archaeometallurgical research contributes to learning about and reconstructing the elements of the old technology [11]. A great role in the reconstruction of artefacts is played by computer programs, which help to transfer historical artefacts into a virtual environment [12].

Helpful for research as well as the dissemination of results, 3D visualizations made on the bases of detailed photographs are used for documenting purposes. To analyze the artefacts that are to be cast from a technological perspective, design drawings have to be prepared, using the appropriate tools. Here, the Blender program was used (Blender is a freeware program for creating three-dimensional graphics). Due to its atypical interface, the program may pose some difficulties; however, it is universal and offers a broad scope of possibilities (like 3D modelling, rendering, and animation making). When recreating the technology for making a specific artefact, the cast itself was not only modeled, but also its mould, core and gating system. This allowed us to create an assembly drawing. A 3D reconstruction prepared in this way and saved in the appropriate format enables us to transfer the process of pouring liquid metal into a mould to the simulation environment (using MAGMASOFT, Flow-3D or Pro-CAST) or to tools that enable 3D printing.

2. Methodology

A set of casting moulds and metal artefacts from archaeological research at the Grzybiany settlement was researched. Their technology was assessed based on the analysis of the surface, structure and microstructure of the casts. There were macro- and microscopic

analyses using light microscopy. Also, qualitative and quantitative tests of chemical composition were conducted with the help of the XRF method. Based on the macrostructure analyses of the artefacts, their 3D visualizations, designs, and 3D prints were prepared. The goal was to recreate the casting technology of the ornamental objects with the help of modern engineering programs. An important task was to reconstruct a zoomorphic pendant using the lost-wax casting method.

3. Researching the chemical composition and structure

In the workshop area, numerous objects (mainly ornaments) were found. The shapes of some of them match the mould fragments, which proves that not only the moulds were prepared in this workshop in Grzybiany, but also the casts. The research showed that the casts were made from copper alloys with varying chemical compositions. There were two-component alloys present of Cu-Sn type, three-component Cu-Sn-Pb, but also multi-component ones, where the presence of Sb, As, Fe and others should be seen as a technological reminder of obtaining raw materials from polymetallic ores. An example of this chemical composition was a small zoomorphic casting (Fig. 5).

Fig. 5. Macroscopic photo of zoomorphic pendant (accession no. 300/78)

The zoomorphic pendant was made using the lost-wax method, as a precision casting in clay mould. Chemical composition tests showed (Fig. 6) that the pendant was made from tin bronze of Cu-Sn type, with the addition of lead as well as a significant share of iron, antimony, nickel and arsenic.

Microscopic pictures (Figs 7 and 8) of surface fragments of the zoomorphic cast show structural elements of regular shapes and relatively high compactness and homogeneity. The fine-grained structure has a dendritic character. Light phases of the components are located in the dendritic spaces, against which there are primary dendritic crystallites of dark hue visible, spaced in an uneven manner.

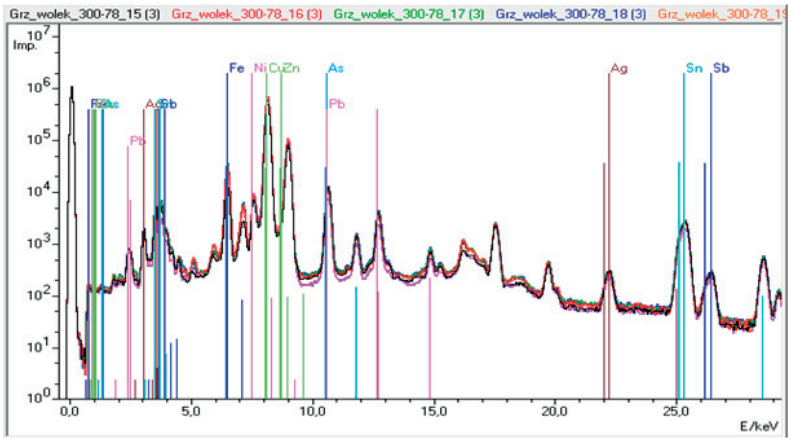

Fig. 6. Fluorescent spectrum of the zoomorphic pendant: C, Sn, Pb, Sb, As, Ni, Fe, Ag and Zn were identified

a) b)

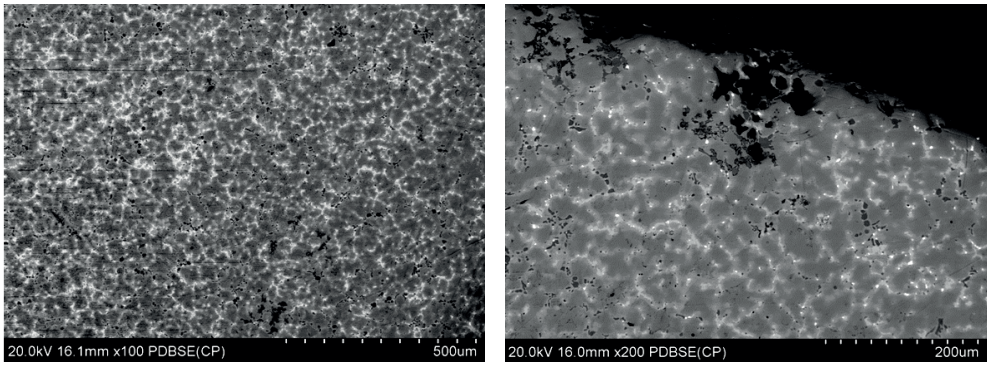

Fig. 7. SEM micrograph: a) center of the sample, magnification 100×; b) at the edge of the sample, magnification 200×

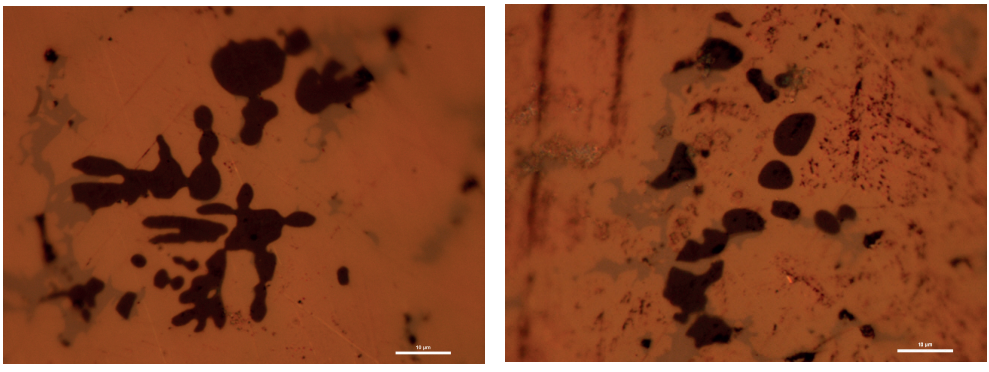

Fig. 8. Zoomorphic pendant microstructure, different shape of precipitates

4. Visualization based on computer modelling

To visualize and recreate the production technology of the casts researched, computer modeling methods were applied. The visualization of artefacts was made for documentation, research, and disseminating purposes. Prior to starting the project, it was necessary to make reference pictures (Fig. 9) that enabled observation of the model during the design process. This made it possible to transfer the artefact into virtual space. This was one of the stages leading to the implementation of model reconstruction of the artefact using modern computer software.

Then, in graphics program Blender 2.69, a symmetrical block was formed that corresponded approximately to the pendant shape (Fig. 10a). The method used for creating this is called box-modeling, and a more-streamlined shape was obtained using a Multiresolution modifier. Thus prepared, the model could be further converted by a virtual-sculpting method. This has resulted in a more-accurate shape as well as showing more-prominent irregularities of the surface. After that, the model was no longer symmetrical (Fig. 10b). The final stage was its grid preparation for applying the texture. It was applied with an additional script called BProjection. After applying the texture and bump mapping, the model was ready to perform the rendering (Fig. 10c).

Fig. 9. Exemplary reference picture

Fig. 10. Computer modelling of the pentant: a) symmetrical model of the pendant roughly corresponding to the original; b) finished model sharped by sculpting, without textures; c) finished model, after adding the texture and bump mapping

Fig. 11. Computer visualization of zoomorphic pendant reconstruction

For taking pictures, it was necessary to create a proper scene. The cycles rendering engine was used. The visualization is presented below (Fig. 11).

At the same time, the models were prepared (Fig. 12), which were then transferred to the software cooperating with a 3D printer. The ABS (*Acrylonitrile Butadiene Styrene*) prints recreated the geometry of the object (Fig. 13).

Fig. 12. Visualization prepared for 3D printing

Fig. 13. 3D printing with ABS

5. Geometric reconstruction of the pendant using the lost-wax method

One of the most important objectives of the research was making a pendant copy at the same scale from recreated material and (what was paramount) utilizing the lost-wax casting method. For this end, computer 3D visualizations were used, which enabled us to make 3D model prints from ABS material.

At the same time, a matrix was made from the natural model with Castaldo Rapid rubber (hardenable by vulcanization), ensuring high fidelity of the recreated detail. The matrix recreated the shape and texture of the zoomorphic pendant (Fig. 14a). Ruby Red modeling wax, characterized by minimal shrinkage and precise detail rendering, was injected into the matrix.

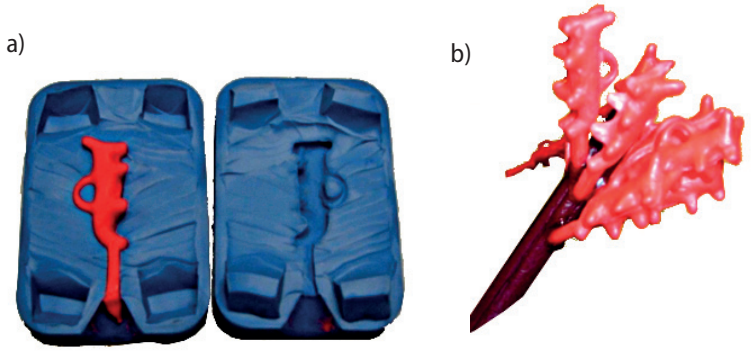

Fig. 14. Matrix for making the wax models (a), modelsconnected with the gating system (b)

Fig. 15. Unpolished cast (a), finished casts (b)

The finishing work consisted only of cutting the gating system off and cleaning and polishing the cast surface. In this way, the cast geometry, its texture and also small casting flaws were copied from the original (Fig. 15).

Wax models that were prepared in this way were joined into a pattern set (Fig. 14b), which was used for making the casting mould. Satin Cast gypsum mass was used for this purpose, the material commonly accepted as yielding the best results and ideal casts.

Once prepared, the mould was subjected to drying and heating according to the set parameters of temperature increase in time (Fig. 16a). The mould was filled (Fig. 16b) with the modeling alloy that had a temperature of 1140°C. This alloy, created according to the formula resulting from research of the chemical composition of the zoomorphic pendant, was determined as multicomponent bronze, consisting of copper, tin, antimony, arsenic, nickel, silver and iron.

a) b)

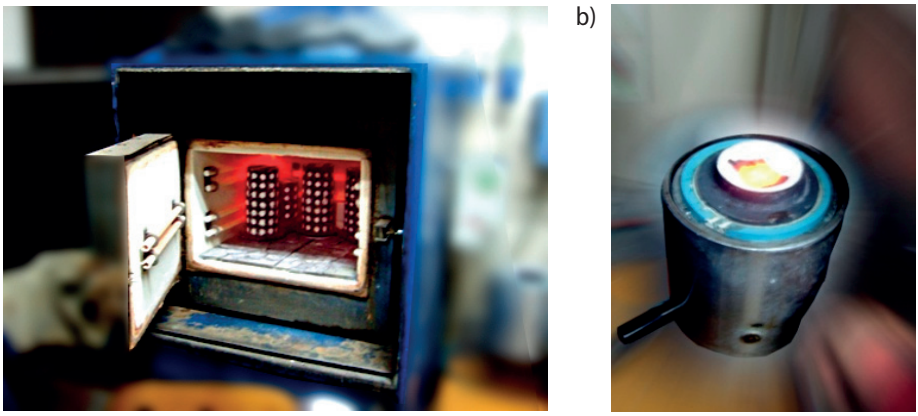

Fig. 16. Firing the moulds (a), Pouring the modelling alloy – multicomponent bronze (b)

The necessity of using high-quality materials resulted from the need to ensure the maximum likeness between the copy and the original pendant.

6. Conclusions

The casting workshop in Grzybiany near Legnica belongs to one of the most significant archaeological sites from the perspective of studies on casting technology in the Bronze and early Iron Ages. During the research of the artefacts from Grzybiany, various analytical and visualization methods were applied. The main goal of the research was analyzing the casting technology used in the workshop under scrutiny, allowing recreating one of the important metal artefacts. A series of tests on casting moulds was conducted, which proved that the lost-wax casting method was used in the Grzybiany workshop. The research of metal artefacts allowed us to assess the alloys used there. For scientific, experimental, and educational purposes a computer visualization was performed, and the zoomorphic pendant was next reconstructed using the lost-wax method.

The article points to the fact that computer programs play an important role in artefact reconstruction, thus enabling the transfer of historical elements into the CAD

environment which, in turn, results in the possibility of further modifications. Once prepared, three-dimensional reconstruction recorded in the appropriate format enables its transfer into the simulation environment of casting liquid metal into the mould (using the MAGMASOFT, FLOW-3D or ProCAST programs) or using tools for 3D printing. Because of their specific shapes, historical artefacts are often impossible to recreate with the use of typical industrial programs. Due to the way the model is created as well as its full grid control, artistic programs such as Blender offer the possibility of reproducing such complicated shapes as the one presented in the article.

Wax models injected into the mould were used, ceramic (gypsum) fired moulds and modelling alloy, prepared according to the formula based on the analysis of chemical composition of the pendant. In this way, a technologically-, structurally-, and chemically-true replica of the pendant was obtained, as well as its computer visualization.

The lost-wax casting method is used in metal artefacts reconstruction because of good dimensional and surface repeatability. The obtained casts keep analogies to the original as far as the texture and small casting faults are concerned, testifying to the old technologies.

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