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COPPER ALLOYS IN INVESTMENT CASTING TECHNOLOGY

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This paper presents research results in the field of casting technology of copper and copper alloys using the investment casting technology, both from historical as well as modern technology perspective. The analysis of exemplary elements of the old casting moulds is included, as well as the Bronze Age casts. The chemical content of various copper alloys was determined and the application of lost wax method was confirmed in the Bronze Age workshop. At present, investment casting method is used for manufacturing high-quality casts, especially products for power engineering that is why it demands respecting very rigorous technological requirements. The casts were characterised based on microstructure research, chemical composition and conductivity in relation to oxygen content.

Keywords: copper alloys, investment casting technology, ceramic forms, casting defects, archaeometallurgy

INTRODUCTION

Historically, investment casting technology was mainly used for casting: tools, weapons and ornaments. Nowadays, this technology is employed in many important manufacturing sectors, both industrial and artistic.

The propagation of the metal usage skills and cast production is connected with the technology of creating models, moulds and casts. Archaeological studies confirm the knowledge of alloy preparation and the application of advanced methods of mould making [1-8]. The wax model method, based on melting the wax before the mould is cast, ensures smoothness and precision of the model reproduction as well as thin wall of the cast. Wax model was covered with many layers of clay, dried and fired in the proper temperature to ensure refractoriness and mould durability. In the Bronze Age, with the investment casting technology arms and ornaments were produced. The fact, that this method was used is attested to, i.a, by the discovery of ceramic moulds workshop (Grzybiany-Legnica, Poland), destined for manufacturing precise casts of bracelets and necklaces made from copper alloys [9]. The research conducted confirmed the characteristic content of the alloys (Table 1) and the usage of multilayer ceramic casting moulds (Figure 1a).

The moulds were made from sand mixture of varying grain, clay and materials of organic origin (Figure 1b), and next they were subjected to drying and firing process, leaving the porosities for letting the gasses escape form the mould.

Table 1 **Chemical compositions of copper alloys from Grzybiany-Legnica (Poland) / wt.%**

No	Concentration / wt. %						
	Cu	Sn	Pb	As	Sb	Fe	Ni
300-78	65,82	19,13	3,92	2,24	2,44	4,01	1,05
001-72	77,17	20,84	0,32	1,68	0,06	0,41	0,14
047-10	46,81	0,00	38,83	0,39	4,18	5,21	1,00

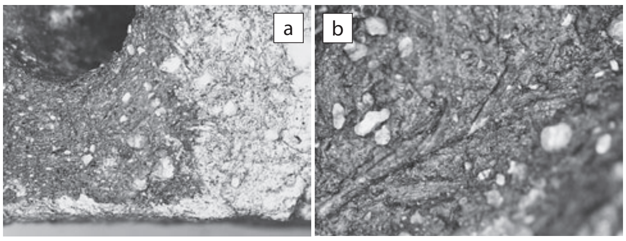

Figure 1 Microscopic picture of archaeological ceramic mould from the Bronze Age, Grzybiany-Legnica (Poland)

For achieving better durability the moulds were covered by external protective and strengthening layer. Defectoscope research of archaeological ceramic moulds led to the discovery of a cavity in the shape of an oval, bracelet together with a gating system, which is directed

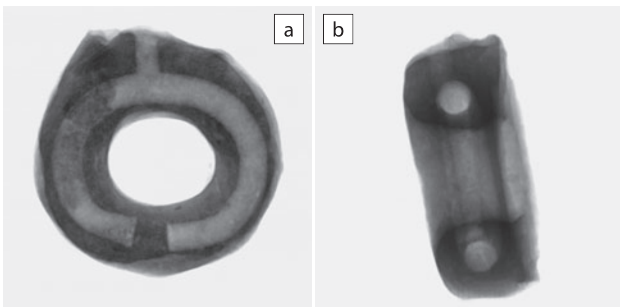

Figure 2 Ceramic casting mould from the Bronze Age, Grzybiany-Legnica (Poland), radioscopic image

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perpendicularly to the surface of the cast (Figure 2). In Figure 2b the circular cross section of the channels of the mould cavity can be seen.

Reproducing the surface relief precisely was the decisive factor behind applying this technique in sculpture and jewellery workshops. At the end of the 19th century the investment casting method was already used in dentistry prosthetics [2].

Nowadays this method makes it possible to make unique artistic pieces from alloys of copper with tin, zinc, lead and also from copper and silver, and also to manufacture both big and very small, precisely cast machine and equipment parts. With the development of many branches of the world's economy, the demand for specialist machine parts increases. These elements are often difficult to make by subtractive manufacturing because of their complex shapes, strongly developed area or special requirements connected with their physio-chemical and functional properties, and also the special quality of their surface. To manufacture these products precise casting technologies are used, according to the investment casting method [10-14]. It is especially common in armaments and aviation sectors, for mining and automotive, power engineering, construction and also in medicine for implant production and in jewellery.

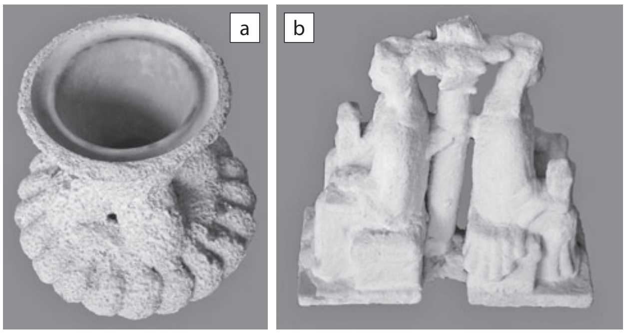

Figure 3 Contemporary ceramic moulds for manufacturing casts: a) industrial, and b) artistic

This technology is used to manufacture turbine blades (Figure 3a), surgical instruments, endoprosthetics, artistic casts (Figure 3b), and also casts made from alloys with special properties.

Technological process of investment casting consists of several stages:

- preparing wax models and assembling them in model sets,
- preparing the ceramic mass and applying it in successive layers,
- melting the wax in an autoclave and holding the moulds within the proper range of temperatures,
- pouring molten metal into the casts, knocking the casts off and cleaning the casts.

Modern copper and copper alloys casting encounters many technical limitations. The reason of limited use of copper for cast manufacturing are the problems resulting from its low casting properties which are high melting temperature, low flowing power, significant casting shrinkage, surface tension and viscosity. Other property, adverse from the viewpoint of casting technology, is high solubility of oxygen and hydrogen in copper, and, thus, the possibility of creating gas porosity. The difficulties of copper casting process in many cases direct our attention to the investment casting method, especially in special casts technology for power engineering. The reason of using copper in power engineering is the fact, that pure copper is characterised by the highest, apart from silver, electrical conductivity. Electrical conductivity of copper depends, first of all, on its very high purity, from metallic impurities as well as oxides and gasses. These high quality standards and also low casting properties allow, with the application of investment casting method, to manufacture high-quality sub-assemblies of of power engineering machines, such as windings, primary rods, high conductivity connectors free from porosity.[8-12]

RESEARCH METHODOLOGY

The elements analysed, belonging to the precision casting where the investment technology was used, are primary windings for transformers used in power engineering. For their manufacturing, because of demands for high physio-chemical properties and surface quality, investment casting technology is applied. It is essential to observe a rigorous technological regime at every stage of the process, beginning with using high quality wax mixtures, ceramic materials, stock materials, melting procedures, copper refining and casting [15-20].

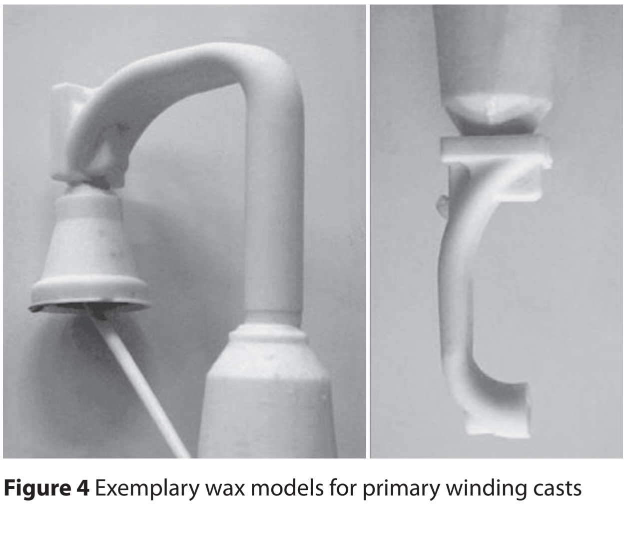

Figure 4 Exemplary wax models for primary winding casts

As part of the research, a set of wax models was made (Figure 4), in a metal die, and next layers of ceramic mass were applied, dried intensively within the proper range of temperatures. The application of successive layers of ceramic mass by immersing in a rotating bath volume in a mixer, was conducted several times to obtain a durable shell. After drying, the ceramic moulds were placed in an autoclave to melt and remove the wax, and then they were heated in a tunnel kiln before being filled with molten metal.

Melting of the metal stock was conducted in an induction furnace, using high conductivity copper and pure copper MOK1 cathode, in a chamotte graphite crucible with protective coating and a layer of charcoal. Refining of the metal bath was conducted with the use of synthetic slags.

A series of melts was conducted: melting under the protective layer of charcoal, refining slag for removing non-metal inclusions, de-oxidation with the help of CuP10 and others, using the copper-based metal stock, in the temperature 1 150 ºC ÷ 1 180 ºC. Liquid metal was cast into ceramic moulds, held in 850 ºC for 6 hours and, directly before casting, cooled down to 650 ºC.

Apart from industrial casts of power engineering windings, also some samples were cast for researching copper quality from the perspective of microstructure and impurities, as well as electrical conductivity.

RESULTS ANALYSIS

To make casts of high quality it is crucial to keep the bath purity at a proper level, most of all, keeping the content of oxygen and hydrogen low. Hydrogen, creating gas porosity, significantly decreases active cross-section of the cast, and, in the microstructure, an active oxygen admixture causes precipitation of large oxygen eutectic zones at the copper grain boundaries, which very strongly decrease electrical conductivity of the casts.

Figure 5 Gas porosity in the copper cast section, made by using the investment technology

The presence of gas porosities in the structure of the cast (Figure 5), as well as non-metallic inclusions, directly influences the properties.

A significant hydrogen content causes the increase of porosity, which decreases physio-chemical properties, this is lowering the density, thermal and electrical conductivity as well as mechanical properties, resulting in the lowering of the properties of the cast. Proper conducting of the copper melt and application of the measures preventing hydrogen solution in copper still can lead to the solving of excess amount of oxygen.

Research of slag and de-oxidation formulas allowed to analyse the efficiency of the latter as well as asses the influence of oxygen in the copper on electrical conductivity. The samples of de-oxidised copper showed varied content of the oxygen, in the range of

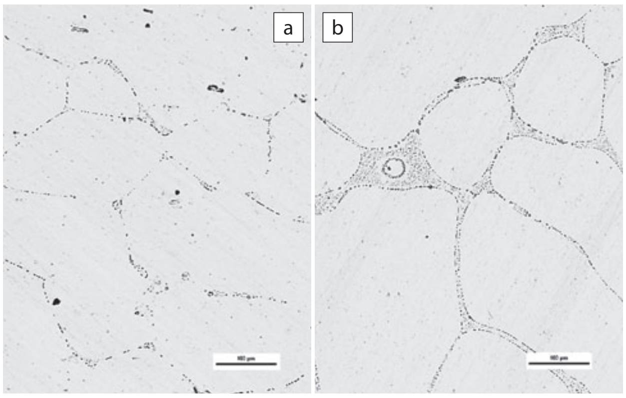

Figure 6 Copper microstructure with the oxygen content of a) 150 ppm, b) 1 000 ppm, magnification 200 x

$55 \div 1870$ ppm. The presence of this kind of impurities leads to changes in the microstructure. There are oxygen eutectic precipitates visible in Figure 6b.

The oxygen presence in copper influences directly electrical conductivity of the material. Depending on the oxygen content in copper, in the range of $50 \div 300$ ppm electrical conductivity changes $48 \div 57$ MS. The results obtained show unequivocally that the oxygen content present in the copper, even below 300 ppm will significantly lower the properties of the manufactured casts for the power engineering.

CONCLUSIONS

In spite of the fact, that investment casting technology was already used in the Bronze Age, nowadays, especially when manufacturing high-quality casts for, i.a. power engineering, it demands respecting very rigorous technological requirements. Properly chosen parameters at every stage of the technological process ensure creating the cast with the highest functional properties.

Special attention should be paid to the metal bath quality, especially its hydrogen content, solid inclusions and especially oxygen. The research provided an opportunity to evaluate the quality of the casts from the perspective of gas porosity, the kind of microstructure and the influence of oxygen on the lowering of electrical conductivity of the copper casts manufactured with investment technology.

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