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ABOUT THE OLDEST TECHNOLOGY OF BRAZING ON THE EXAMPLE OF ARCHAEOLOGICAL FINDINGS — A GOLDEN GOBLET FROM TRIALETI AND A MUFFLE FROM KVATSKHELI

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Considering the stages of human development from a material and spiritual point of view, a significant achievement in this field is the discovery and study of metals, as well as the invention of methods for their processing. The result of activity and constant search in this direction is the creation and development of metallurgy. The masterpieces of jewellery are presented to us as a continuation of these processes. An integral part of these processes is the accumulation of knowledge through observation and improvement of the learned rules and techniques. One of the most important of them is the brazing process as a method of joining finished metal parts that was invented by a human at an early stage of human development. 8 Ref., 8 Figures.

K e y w o r d s : brazing, reaction and substance brazing alloy, metallic gold, brazing of artifacts

The aim of this study is to present the tools and technologies existing in ancient jewellery workshops and also to make the conclusions about the composition of the brazing alloy and the methods of its application based on the results of the works on joining parts using brazing.

Based on the made observations, I can say that on the oldest products, traces of two types of brazing alloy are observed. The first is «substance brazing alloy», during which to a gold or silver product a melt of a small amount of gold or silver (from the same metal that the product is made of) is applied, with the addition of a special alloying metal.

And the second, the so-called reaction brazing alloy, which contains a complex chemical compound of organic and inorganic substances. Under the influence of temperature, as a result of reducing reaction, this compound melts the surface of the products and firmly joins the smallest parts between each other.

Today, at modern jewellery workshops, during brazing of silver or gold products, only the first method is used. That is, to achieve the desired results and the required temperature, «substance brazing alloys» are used. For their manufacture, gold or silver is taken, however their amount should be small and with the addition of alloying metals. The latter include elemental silver, copper, lead, zinc, tin, cadmium, etc. By introducing these metals into the basic composition of gold or silver in various proportions, special alloys are produced, that strongly join two parts of the product with the use of appropriate fluxes and temperature [1].

During brazing, gas torches are used, among which there are many types; we can use them based on the specified task. They are quite easy in using and allow the craftsman to make an efficient processing of the details. These appliances easily regulate the flame with the help of a special valve, increasing or decreasing the gas flow [1].

In the process of changing the cultural epochs of human development, jewellery began to flourish and the primary metal gold, necessary for such a work was considered to be sacred, it was considered to belong to the gods [2].

The works of many authors of the Middle Ages, which have survived to this day, tell us both about the metal processing in general as well as about jewellery: Al Birun, Theophilus, Arraz, Agricola, Beringuchio, Cellini, Vakhtang VI, etc.

Considering the history of processing precious metals, a researcher cannot ignore one of the most important manuscripts belonging to the pen of Theophilus Presbyter, Benedictine monk, who worked in the XI–XII centuries [3].

For our study, the treatise of Theophilus was particularly interesting as far as it discusses the methods for preparing the gold base for cloisonne enamel and the manufacture of partitions for enamel. It also provides some advice on the preparation of brazing alloy and its application [3].

Theophilus considers two types of brazing alloy:

- produced by alloying gold or silver;
- manufactured from chemicals.

The second type of brazing alloy, as indicated above, is prepared from such organic and inorganic compounds, which melt the surface of gold or silver at a temperature of 900–920 °C and join two parts between each other. Such a method originated in the distant past of mankind, and the advanced nations of the ancient world used that method to create exquisite art forms such as filigrain and granulation based on the processing of such natural materials as chrysocolla (aqueous copper silicate $CuSiO_3$ nH_2O) or malachite (aqueous copper carbonate $Cu_2[CO_3](OH)_2$). According to Theophilus, the composition of the brazing alloy is valuable because it describes a method for producing this brazing alloy using artificial chemical processes in the developed Middle Ages [3].

In his treatise the methods of brazing jewellery are described by the Italian jeweler and sculptor of the XV century Benvenuto Cellini. He describes the contents of alloying (substance) brazing. As far as defects are almost always formed during calking in the form of holes and cracks, it is necessary to fill them with this type of brazing alloy [4].

He proposes to eliminate the mentioned defects only with the help of substance brazing, since reaction brazing is not able to eliminate the errors because of the lack of substance. The latter allows melting the surface of the precious metal, which is a good method for joining each small part.

P. Theophilus also indicates the need in preparation of alloying and substance brazing. However, unlike Cellini, instead of silver he introduces copper into gold [3].

The king Vakhtang VI, a Georgian scientist of the 17th–18th centuries, also writes about alloying gold with copper in his treatise «Book about the preparation of solutions and chemical transformations» [5].

These examples clearly indicate the existence of universal uninterrupted knowledge in the field of processing precious metals. And although they were always strictly hidden, nevertheless they spread and adopted the characteristic features of one common culture of mankind.

After describing the application and content of the brazing alloy, Theophilus writes about the way a craftsman should do his brazing work. He points out on how a space in a bunch of burning coal can be created so that the product does not directly come in contact with fire, and a certain temperature would uniformly surround the parts to be joined. That is, as also Cellini later did, he is trying to create a muffle-like space in a bunch of burning coals. Although Theophilus is familiar with the method for manufacturing iron muffle for calcination of enamel and he even describes that method [3], he still offers another

Artifact, muffle «Colchian cover»

method for brazing, apparently in order to be able to follow the process. And the iron muffle necessary for calcination of enameled plates is described by him as follows: «Put the plate into fire on a thin sunken tray with a short metal handle. Cover it with an iron lid, which should be concave like a small bowl and also completely covered with holes ... This lid should also have a small ring in the middle, by means of which one could cover and open it ... ».

The small appliance made of iron, described by Theophilus, which apparently was used in the Middle Ages, consists of two independent parts: a lower concave tray with a handle and a round hemispherical iron lid with a ring. Combining of these two parts creates an enclosed space — a muffle. The name «muffle» comes from the Latin word muffla, in French moufle, which means «coupling» or «closed».

It is interesting to know whether such a appliance existed in earlier times, and what modifications could exist or what materials had to be used.

In 2012–2013 in the National Museum of Georgia I realized the project «On the Traces of Lost Technologies — Cloisonne Enamel», within the framework of which it was planned to investigate the peculiarity of technologies of a Georgian-Byzantine cloisonne enamel. In the process of the work on the project, I was able to identify an artifact from the Vani fortification**,** a cone-shaped product made of sheet iron with many holes, dating back to the middle of the 1st

Copy of the muffle «Colchian cover»

millennium BC. This appliance consists of two parts made of hammered iron. The same as in the muffle described by P. Theophilus, it has a lower concave part and a tightly closed conical-shaped lid with a metal ring at the top.

After studying and reconstructing the so-called Theophilus lid, it became easier to identify the lid from Vani. That was definitely a muffle. As soon as we put this appliance into fire, a high temperature is formed inside the chamber and, as experiments showed, that provides us the ability to glaze small ceramic products, calcinate the enameled plate, and also join (braze between each other) the finest parts of gold and silver. The reconstruction of the described product and many experiments showed that it meets the requirements for all of the abovementioned jewellery operations.

From all the mentioned above it was concluded that P. Theophilus, creating his treatise, knew and used the traditional knowledge of the jewellery workshop of the ancient world. The artifact from Vani was called a «Colchis cap» by us [6].

Naturally, the question arises whether such an appliance should have been known in earlier times and that in the design of the Colchis cap the usefulness and wisdom of the knowledge of the ancient craftsmen is seen.

Over the long years of work in this area, my attention was drawn to two products of refractory clay covered with holes, which are stored in the National Museum.

Artifact, «golden goblet from Trialeti»

One of those two artifacts was discovered during archaeological excavations in the Kartlii district near the village of Urbnisi on the Mountain Tvlepiya [7] and the second one in the Southeast Georgia in the Dedoplistskaro region. They date back to IV–III thous BC. One of those two lids, found in the village of Urbnisi, has a lower part that fits perfectly with the mentioned clay lid and was found by archaeologists in 1956.

In 2018, at the National Museum of Georgia, we realized a scientific project called «Wisdom embodied in gold — a golden goblet from Trialeti». Within the framework of the project, I had to study the technology of creating a historical cultural monument, which was decorated with applied ornaments and various decors of the golden goblet, found in the Southeast Georgia on the Trialeti Range, the famous center of the kurgan culture in the 1930s and refers to the beginning of the II millennium BC.

Technologically, this goblet is the object of a very complex design. There is no such kind of jewellery, applied even in later eras, which would not have been used in this goblet. It is decorated with carnelian, azure, agate, amber and finely processed minerals. And such the most beautiful product decorated with filigrain and granulation, cloisonne forms are brazed-in filled with a coloured jewellery paste. It was found that this goblet was made by local jewelers and represents an example of the finest art that has no analogue [8].

First of all, during the investigation, I was interested in how many brazing methods were used by the craftsman to create this goblet. After examinations under a microscope, it became clear that the gold sheet plates were brazed-in using an alloyed or substance method. This is confirmed by the fact that in some places unmelted rectangular fragments of brazing alloy were preserved.

This indicates that some brazing alloy plates were prepared in an alloyed manner that did not melt during the first heating, and the craftsman was careful

Unmelted fragments of substance brazing alloy on the artifact golden goblet from Trialeti

not to heat the product for the second time. Just because of the fact that in some places the details of the product were not thoroughly brazed, during the burials throughout the centuries, the goblet was deformed and as a result, the applied ornaments were partially torn off from its body.

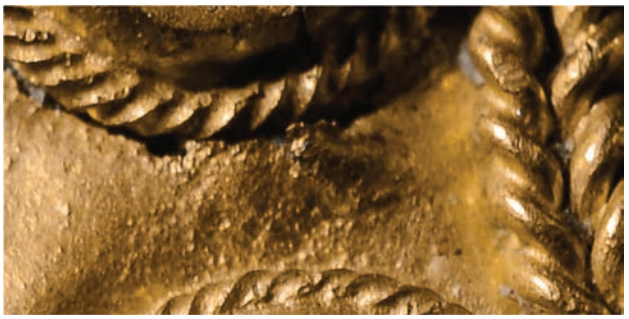
A detailed examination reveals that the craftsman also applied another type of brazing alloy. In particular, the applications on the goblet itself, filigrain on the leg, frames for stones and granulation are clearly brazed by the method that was used in the subsequent centuries to join partitions, filigrain and granulation. That was the method described by P. Theophilus and later by Cellini. Applying this brazing alloy on the surface of the product, traces of light erosion are revealed.

This type of brazing alloy acts on the surface of the metal without penetrating inside [5]. The indicated method of brazing precious metals for joining balls of granulation, golden partitions and the finest filigrain, was used by the nations of ancient civilizations. According to observations, to join the larger parts, alloyed or substance brazing alloys were used. This was once again confirmed by a detailed study of the chemical composition of the Trialeti goblet using a portable nondestructive X-ray fluorescence analyzer. The four parts of the goblet were studied that are interesting to us. Here are the results of this study:

Edge Au–83.4; Ag–11.9; Cu–3.6; Fe–0.291;
Middle
outside part of the goblet Au–83.1; Ag–12.9; Cu–3.59; Fe–0.348;
Filigrain Au–82.8; Ag–11.7; Cu–4.55; Fe–0.283;
Leg of the goblet . . . . . Au–80.1; Ag–15.7; Cu–3.31.

These scientific observations confirm the many-year studies in this area. In particular, at the places of joint, an excess of alloyed metal is observed unlike in the main area. In the place where filigrain is located, a slight increase in copper content is observed. That is correct, as far as when a brazing alloy of the reaction type is used, the principle of the reduction of copper from the oxide state to the state of the metal works. As a result, the thinnest copper film is formed on the surface of gold, which under the influence of high temperature is strongly joined with gold and forms a layer having a low melting point. This phenomenon occurs as fast as a flash and very carefully joins small parts between each other.

The conducted chemical analyses on the composition of the goblet show an increase in silver content in the places where substance brazing alloy had to be applied. We can make a bold assumption that this brazing alloy is made of gold with the addition of silver and copper, where silver prevails.



Traces of reaction brazing alloy
on the artifact golden goblet from Trialeti

I think that the results of the study of the Goblet from Trialeti are of great importance in the field of technologies for studying artifacts and brazing.

All of the abovementioned is confirmed by the recipes of the brazing alloy and the methods of their application described by P. Theophilus and B. Cellini. Both authors emphasize that for a reliable joining of large parts, a craftsman should use metal or substance brazing. The authors of the treatise apply it in a sawn state [4].

The fragments of unmelted brazing alloy and erosion around the inlaid and granulation-covered part of gold found on the golden goblet from Trialeti, make it clear that in that region already at the beginning of the II millennium BC both types of brazing alloy and methods for their application were known.

Conducting the investigations with the Trialeti goblet, I tried to find out what kind of tools were indeed used by the creator of this masterpiece. As far as in the jewellery a great importance is paid to joining parts, in the course of the project we reconstructed the ancient instruments of labour and tools used during such ling of work. As was confirmed during the experiment with the «Colchian cover», it turned out to be a jewellery appliance for calcination of products. We conducted the same experiments with the muffle from Kvatskheli, which is entirely made of clay and is very similar to the «Colchian cover». We were interested whether an ancient craftsman could use that appliance to perform operations requiring a high and stable temperature.

According to its design, the Kvatskheli muffle consists of two parts, the lower one is the chamber for fire and the upper one adjacent to it, is the lid reflecting heat. In turn, the lower part, intended for fire, fits tightly to the hollow sphere with its edge, the same sphere stands on three legs joined by a common bottom. Below, this sphere-shaped bowl has a hole for air supplied into the chamber. Inside the combustion chamber, a very high temperature is formed, heating air in the lower part. Due to a strong fire, the bottom of the chamber is incandescent and it heats up air in the sphere. A jet of hot air is mixed with cold air enter-

Ceramic muffle from Kvatskheli

ing from the lower sphere and is supplied warm into the chamber with burning coals. It is known that with the help of warm air the fuel heats up twice as fast and burns more economically and stably accumulates heat under the reflective lid. This creates excellent working conditions.

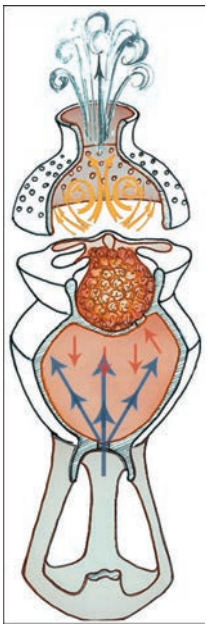
We created a muffle furnace from clay similar to that from Kvatskheli and made a lot of experiments with it.

In the chamber for fire under the reflective lid, heat is formed and maintained and the temperature is more stable and uniform there than in modern torches for brazing, which do not allow creating the fire that grows in its intensity, necessary for brazing parts. Whereas in the muffle, created on the example of the Kvatskheli artifact, the manufactured product is heated easily, and the most important is that heat is spread uniformly over the entire surface. This is a prerequisite for high-quality successful brazing.

With the help of theoretical studies and numerous practical experiments, we proved that with the use of the Kvatskheli type muffle, many jewellery operations such as melting gold or silver in small crucibles, calcinating of the hammered parts and their joining using brazing can be carried out. This muffle represents a laboratory appliance of a complex design, which was used by ancient craftsmen-jewellers in their workshops already at the end of the 4th and beginning of the 3rd millennium BC.

The appliances of a similar type dating back to later centuries are also found by us during excavations. A striking example here is an iron muffle with windows found during excavations in the Vani fortification (Western Georgia), which was named the «Colchian cover» by us. And later on, P. Theophilus writes about the lid for calcinating enamel in his treatise.

Thus, the types of brazing carefully studied by us on the example of the Trialeti goblet and the ex-



Principal scheme of functioning of «ceramic muffle» from Kvatskheli

periments carried out with the Kvatsheli muffle give ground to suggest that almost at the entire territory of modern Georgia, there were craftsmen of the highest class, who perfectly mastered the technology of processing non-ferrous and precious metals. The artifact, dating back to the beginning of the 2nd millennium BC, found by archaeologists on the Trialeti ridge, evidences that there was a whole system of jewellery workshops based on deep knowledge. And our artifact, a golden goblet from Trialeti is a worthy confirmation to that.

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