Archaeo-metallurgical Analysis: A Study of the Metallurgy in Early Medieval Societies at Moghalmari, West Bengal

Anustup Chatterjee
Assistant Professor
Department of Mechanical Engineering
Techno International New Town
Kolkata -700156
Email: anustupnarendrapur@gmail.com

Abstract

Archaeo-metallurgical study in early medieval Bengal traces the history and development of metalwork. West Bengal as an integral part of eastern India has a very old tradition of iron technology, as indicated by the metal objects obtained from various archaeological sites. All materials collected from these archaeological sites in West Bengal prove that the ancient alchemy and metallurgical science practiced in this region were rich and vast. The detailed description of metallurgical processes and intricate properties of minerals and chemicals in the 10th-11th century alchemy text, referred in the Rasaratna Samuchchaya is yet another proof of the high level of knowledge of metallurgy. Metals have a very close relationship with human civilization and the phases attributed to different stages of cultural growth are dominated by the metals being used at a particular period.

Metal objects found from various early medieval sites of West Bengal provide a unique opportunity to study the development of metalworking fashion and technology. A number of excavations & explorations have been conducted to investigate the societal structure and material culture of this period. The study of metal technology also helps us to know the cultural development and craftsmanship.
The present study involves scientific analysis of metal objects (Bronze) obtained from a very culturally rich archaeological site Moghalmari in West Bengal. The method used for scientific analysis such as X-ray diffractogram which has revealed the composition of materials. In this study Scanning Electron Microscope (SEM) has also been used to analyse the microstructure of the sample. After performing different tests on the collected sample, the results have provided a clear picture regarding the purity, composition of the metal.

**Keywords:** Archaeo-Metallurgy, Ancient Metals, Scientific Analysis, Early Medieval Sites, Moghalmari

### I. INTRODUCTION

Archaeo-metallurgical analysis is associated with the material science and metallurgical engineering studies. It deals with the ancient metal like copper smelting, bronze crafts, copper-bronze alloying technology, as well as the metal and mineral transaction. The present work is motivated from the Archaeo-metallurgical study. From the site of Moghalmari a number of artefacts have been excavated like pottery, stucco images, terracotta objects, stone objects, bronze objects which reveal the human activities and culture of the then period. This research is focused on bronze content, with the aim of determining the material handling and processing techniques that were in use at the time.

### II. OBJECTIVE OF THE STUDY

The key aim of the paper is to study the materials using various techniques such as X-ray diffractogram, which will show their structure. The microstructure of samples collected from excavated sites can also be examined using a Scanning Electron Microscope (SEM). The findings of numerous experiments conducted on the extracted samples disclose a clear picture of purity and coherence.
III. AREA OF STUDY

This study is based on excavated site of Moghalmari. This site was initially excavated by Department of Archaeology, University of Calcutta and further excavated by the State Directorate of Archaeology. The village of Moghalmari (21°57’ N and 87°16’ E) is located in the district of Paschim (West) Medinipur’s Dantan police station. On national highway no. 60, the village is about 5.2 kilometres north of Datan town and 46 kilometres south of Kharagpur railway station. The Moghalmari archaeological site was on the left bank of the Suvarnarekha River, which now flows some 4.5 kilometres west of Maghalmari. Bronze sculptures are one of the important types of artefacts which have been collected from this archaeological site. Figure 1 shows the archaeological site of Moghalmari where excavations have been done and the sample collected from this site. (Datta, 2010).

IV. DESCRIPTION OF COLLECTED METAL SAMPLE

The present analysis was conducted with a small portion from the corner has been cut off from the collected bronze sculptures.
Initially it was in corroded condition. Since the material is bronze it has been converted to oxide after coming in contact with the oxygen present in the surrounding air which is evident from the greenish colour of the sculptures. Due to heavy corrosion the sculptures have become brittle and require careful handling. Figure 2 shows one of the Bronze sculptures that have been collected from the archaeological site Moghalmarci.

V. METHODOLOGY

For the purpose of the study bronze samples have been collected from the site Moghalmarci. The excavated bronze sample from Moghalmarci has been taken for limited metallographic analysis. A small portion from the corner has been cut off for the test. For scientific analysis X-ray diffractogram, Optical Microscope (OM), Scanning Electron Microscope (SEM) and SEM EDX have been used.
VI. SCIENTIFIC ANALYSIS

From the small portion of the excavated bronze sample had been taken for limited metallographic analysis. Before proceeding for the analysis, the sample has been measured. Figure 3 shows the steps involved in measuring process and indicating the small portion that has been collected from the mother material.

The specimen has firstly undergone X-ray diffractogram test for identification of the material composition. The experimental result confirms that the metal is bronze which is composed of mostly copper and tin. This bronze sculpture was produced by rural artisans of the early medieval period. The study till now has revealed the presence of Cu-Sn (Copper-Tin) phase but the exact identification of the particular phases has to be ascertained. The traces of copper oxide (Cu$_2$O) certify the corroded natural element of the sample as well as oxide slag of copper.
Figure 4 clearly indicates the presence of Cu-Sn and Cu2O. The X-ray diffractogram has certain limitations. The SEM-EDX experiment was used to understand more about the structure of the sample. More details about the composition is revealed as a result of this experiment. The elements present in the bronze sample are clearly seen in Figures 5 and Table 1. SEM-EDX findings of an etched bronze sample reveal a small volume of iron and nickel in addition to copper and tin. The SEM-EDX microchemical study shows only a limited number of details regarding the existence of main element copper and minor elements tin, nickel, and iron.
Compositions:

Table 1 Weight percentage of composition

<table>
<thead>
<tr>
<th>Elements</th>
<th>Weight (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper (Cu)</td>
<td>79.8</td>
</tr>
<tr>
<td>Tin (Sn)</td>
<td>9.07</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>3.16</td>
</tr>
<tr>
<td>Nickel(Ni)</td>
<td>2.14</td>
</tr>
</tbody>
</table>

According to the EDX report, the sample suggested a copper alloy with only a small number of elements. The inclusion of nickel and iron in this specimen lends more weight to the bronze sculpture. Results show that the weight percentage of copper is very high whereas iron and nickel weight percentage is very less. Iron and nickel was doped in the parent material for giving more strength and stability in the sculpture.

Figure 6 indicates the area of the specimen on which the SEM-EDX experiment has been done.

In second stage of SEM-EDX another area has been selected for another set of operation.

Figure 7 indicates the area on which another set of SEM-EDX is done. SEM-EDX microanalysis identifies tin as a segregated element. It may be due to the presence of some residual metal.
It is well known that tin nickel could have originated from the primary ore of Eastern Indian chalcopyrite. Chalcopyrite is the most important copper ore, since it is a copper iron sulphide mineral. \( \text{CuFeS}_2 \) is its chemical formula, and it crystallises in a tetragonal system. It is brassy to golden yellow in colour and has a Mohs hardness of 3.5 to 4. It has a distinctive green tinged black streak.

In the bronze material the limited amount of iron indicates a successful copper refining extraction technology, as iron was almost completely removed during freezing according to the Figure 8.
**Cu-Sn Phase Diagram**

Under slow heating or cooling, phase diagrams demonstrate the relationship between the phases existing, alloy structure, and temperature. Slow heating or cooling causes the atoms inside a metal to shift about and achieve equilibrium, resulting in a stable alloy. Cu-Sn alloy phase diagram gives the structural morphology of the material in particular alloy percentage and at particular temperature. Figure 9 is clearly indicating the percentage of Cu-Sn in X axis and the temperature in Y axis at which casting has been done. In the SEM-EDX result the weight percentage of Sn is 9.07% which indicate in phase diagram that is in β phase. In this β phase the metal structure of the element should be **Face Centered Cubic (FCC)**. There are eight atoms at the corners of the unit cell and one atom centred on each of the faces of the FCC arrangement. The face atom is shared with the cell next to it. Four atoms make up FCC unit cells, with eight eighths at the corners and six halves on the faces.

![Figure 9 Phase diagram of Cu-Sn](image_url)

Figure 9 is clearly indicating the percentage of Cu-Sn in X axis and the temperature in Y axis at which casting has been done. In the SEM-EDX result the weight percentage of Sn is 9.07% which indicate in phase diagram that is in β phase. In this β phase the metal structure of the element should be **Face Centered Cubic (FCC)**. There are eight atoms at the corners of the unit
cell and one atom centred on each of the faces of the FCC arrangement. The face atom is shared with the cell next to it. Four atoms make up FCC unit cells, with eight eighths at the corners and six halves on the faces.

**The atomic packing factor (APF)**

The atomic packing factor (APF), also known as packing efficiency or packing fraction in crystallography, is the proportion of a crystal structure's volume occupied by constituent particles (Park et al, 2007). It's a one-dimensional number that's still smaller than one. By convention, the APF of atomic structures is calculated by assuming that atoms are solid spheres. The spheres' radius is set to the highest value that prevents the atoms from overlapping. The packing fraction of one-component crystals (those containing only one type of particle) is defined mathematically by

\[
\%\text{APF} = \frac{\text{Volume occupied by Effective number of atoms} \times 100}{\text{Volume of Unit Cell}}
\]

\[
= \frac{4 \times \frac{4}{3} \pi r^3 \times 100}{\frac{a^2}{x^2}} = \frac{16 \pi \left(\frac{a}{2\sqrt{2}}\right)x100}{a^2} = 74\%
\]

Where \( r = \frac{a}{2\sqrt{2}} \)

So, the APF for FCC is 74%. Figure 10 clearly shows

![Figure 10 Cross-sectional image of FCC structure](image-url)
the position of atoms in the FCC structure. The bonze consists of Copper and Tin atom which is basically substitutional solid solution. In this substitutional solid solution Copper (Cu) is a solvent and Tin (Sn) is the solute which is nicely shown in the Figure 11.

![Figure 11 Position of Atoms](image)

A substitutional solid solution is basically a mixture of two kinds of atoms in which one type of atom can substitute for the other. Here Tin (Sn) atom substitute the Copper (Cu) atom.

**Optical micro-structural Image analysis**

In next phase of experiment optical microscope gives a clearer idea about the microstructure of the specimen.

![Figure 12 Unetched condition of microstructure of sample](image)
In Figure 12 optical micro-structural image shows in unetched condition, equiaxed grains of copper alloy are there. Dendrite like a crystal structure can be seen that resembles a tree like structure. Hence it proves that metal had been cast without further forging treatment. So, it signifies less efficiency of casting process.

![Optical Microstructural Image of Sample](image1.png)

Figure 13 Etched condition of microstructure of sample

Figure 13 depicts an optical microstructural picture in etched condition. The reddish (alpha) copper grains have been found in primary metallography readings, Cu-Sn solid solutions are there and slag entered into the grain. This slag makes copper alloy weak.

**Structural analysis through Scanning Electron Microscope (SEM)**

The optical microscope has a limitation. Scanning Electron Microscope(SEM) was used to read off the shortcomings in the future study of the sample.

![SEM Image of Sample](image2.png)

Figure 14 SEM image of Sample
From the Figure 14 SEM images have shown some white zone present in the microstructure in etched condition. A rough dendritic pattern can also be discerned from the overall metallic component. However, there are far too many non-metallic materials, which do not expose strong casting experience.

VII. CONCLUSION

From this research, we understand about the use and composition of bronze prevalent in the early medieval century. People preferred to use alloy materials like bronze, which is a mixture of copper and tin. Evidently, the X-ray Diffractogram analysis reveals the presence of both Iron and Nickel, which contribute to the structure's strength. Even in the early period, people were able to create a Face Centered Cubic (FCC) crystal structure as evident from the sample belonging to the site of Mogholmari. In early medieval period skilled persons not only knew about melting objects, moulding and casting them but also, they were very good at it. However, the microstructural analysis undertaken during the study indicates the existence of a Dendrite-like crystal structure, suggesting that the casting process is less effective than the modern technologies. Studies using the Scanning Electron Microscope (SEM) show the presence of non-metallic components in the sample and indicate that they lack thorough casting experience. Due to the inefficient casting process and the presence of non-metallic components have led to the brittle nature of the metal. It may be inferred from the present study that even though, people of that era were not very skilled in the casting method, still they were able to effectively make a sculpture using the casting process to achieve the perfect form and scale during the 9th-10th centuries. Despite the fact, that we now have a great deal of knowledge and experience in the casting process, it was primarily initiated by them.

Thus, in conclusion, it can be said that the current research has thrown considerable amount of light on the culture of the early medieval era, when people were used to casting, material handling, and moulding in the desired shape and scale in their day-to-day life still there is
significant future scope of research which would consist of in-depth archaeo-metallurgical analysis.

VIII. ACKNOWLEDGEMENT

I would like to acknowledge and convey my gratitude to Prof. (Dr.) Durga Basu for me guiding through this research. I am also grateful to my wife Asmita Basu Chatterjee for constantly supporting me in my research. Last but not the least I need to mention about Dr. Utpal Maity, who has helped me with some vital information about this research.

IX. REFERENCE


[3] Kokatanur, R. B. AN INTRODUCTION TO ANCIENT INDIAN COINS.

