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ORIGINAL STUDY

The Neutron Imaging Studies of the Metal Archaeological Objects from the Eleke Sazy Complex

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Abstract

The internal structural features of large metal objects found in the cultural and memorial complex of Eleke Sazy in the Republic of Kazakhstan were studied using neutron radiography and tomography. Bronze plate, arrowhead, and fragment of metal bit were studied. The 3D models of the studied objects were reconstructed, the spatial distribution of metals and corrosion products were obtained, and soldering restoration joints were identified.

Keywords: Neutron radiography and tomography, The cultural and memorial complex of Eleke Sazy, Cultural heritage studies, Metal archaeological objects

1. Introduction

The Eleke Sazy Cult and Memorial Complex [1,2] is located in the Tarbagatay district of the East Kazakhstan region of the Republic of Kazakhstan. This archaeological complex is interesting for the study of aspects related to the construction, architectural art, and religious worldview of the ancient Turkic tribes and settlements [3], and reflects ethno-social and cultural processes in Central Asia, associated with the emergence of the ancient Turkic onto the historical scene [4]. Among the archaeological finds are prestigious silver and gold objects and fragments, presumably belonging to a deceased kagan, which categorizes the complex as an ancient historical Turkic site of the “kagan-princely” type [2]. The preliminary results of the analysis of archaeological findings indicate that the active period of evolution of *On ok eli* occurred between the middle of the VII century and the middle of the VIII century.

In addition to rich jewelry and clothing items [5,6], large numbers of chain mail fragments made of iron and copper rings, as well as bronze buckles and straps, weapons, household items, iron and bronze stirrups, spring buckles, arrowheads, and bit were found. All these objects are valuable historical sources necessary for understanding the socio-political structures of the Khaganate, religious traditions, and ceremonies of medieval steppe empires [2]. It is not surprising that archaeological findings from the Eleke Sazy complex are actively investigated using both traditional and modern natural-scientific techniques [7,8]. And it should be mentioned that traditional methods such as X-ray fluorescence analysis and electron microscopy have a significant penetration limitation, as they can only penetrate a certain depth into the metal material [9,10]. Therefore, more and more researchers attract the neutron non-destructive diagnostic techniques [11–14] to gain deeper insights into these objects. One such method is neutron radiography and tomography [15,16], which provides detailed information about the inner structure of rare archaeological objects [17,18] without damaging them. These neutron methods are

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based on varying degrees of attenuation of the intensity of the neutron beam when passing through materials of different chemical composition or density [19]. This makes it possible to visualize the distribution of phase inhomogeneities and hidden internal structural elements of studied objects, including metal ones, without limiting the depth of penetration, even in comparison to X-ray methods.

In the Republic of Kazakhstan, there are opportunities for non-destructive neutron studies [20,21]of archaeological materials at the WWR-K research reactor in the Institute of Nuclear Physics, Ministry of Energy of the Republic of Kazakhstan in Almaty. This work presents the pilot neutron structural study of several archaeological objects like a bronze plate, three-leaf arrowhead and bit.

2. Experimental

Several metallic objects from the Eleke Sazy Complex were chosen for neutron non-destructive experiments. The photos of these objects are shown in Fig. 1. The first object is a bronze plate with movable handles. It has a length of 350 mm, a width of 490 mm and an average thickness of 0.4 mm. The second item is bronze bit wrapped in a spike-shaped plate. Since the era of early nomads, the steppe and mountainous regions of Eastern Kazakhstan have been characterized by a distinct dynamism of horse equipment. Its study is essential for determining the chronological framework and comparison with early nomadic and early Turkic sites [22]. This time period of the development of Eastern Kazakhstan includes long chronological stages: early Saka, late Saka and the era before the ancient Turkic time. It is assumed that it is very important to study the equipment of riding horses, which is a design that reflects in a concentrated form important aspect of the material culture of these periods [6]. We also investigated the arrowhead (Fig. 1). It has an elongated triangular shape of the blades and holes on them, but differs from all known types by arrows [6]. The arrowhead with the wide blades with holes gives some originality for the archaeological object.

To study the internal structure of the above-mentioned archaeological objects, experiments using neutron radiography and tomography were conducted at the TITAN experimental station, located on the first horizontal channel of the WWR-K research reactor [20]. Due to the different levels of attenuation of the neutron beam intensity when passing through materials with different chemical compositions or densities, it is possible to gain information about the internal structure of materials on the micron scale [18,23]. A neutron beam with a dimension of 20 $\times$ 20 cm was provided by a collimator system. The characteristic L/D ratio, where L is the distance between the input aperture of the collimator system and the sample position, and D is the diameter of the input aperture, was of 350. The integral flux of thermal neutrons at the sample position was 7.2 (2)x10^6 neutron/(cm^2*s). Neutron radiographic images were obtained using a detector system based on a ^{6}LiF/ZnS scintillation screen with images recorded by a highly sensitive video camera based on a CCD matrix (HAMAMATSU, Japan). The tomographic experiments were prepared using a system of goniometers with an angular rotation step of 0.5°. The neutron images obtained in the experiment were corrected for background noise from the detector system and normalized to the incident neutron beam using the ImageJ software package [24]. Tomographic reconstruction of angular neutron projections from the studied metal objects was performed using the SYRMEP program [25]. The FEI AVIZO 3D 8.1 software package was used to visualize and analyze the obtained 3D data.

3. Results

Several neutron radiographic images of various parts of the bronze plate are shown in Fig. 2. It can be seen that neutrons easy penetrate into the thickness of the material, and various structural elements in this bronze plate can be visualized. Two movable handles are

Fig. 1. Photographs of examined metal products.

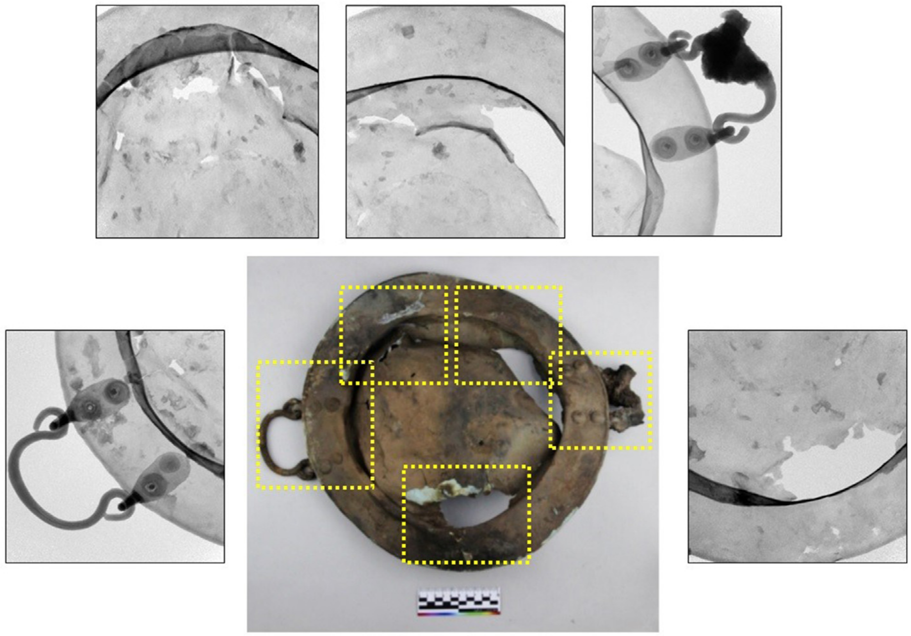

Fig. 2. Normalized neutron radiographic images obtained from different areas of the bronze plate.

attached to the plate by means of double bronze rivets. One handle is strong affected by corrosion products, which is indicated by severe degradation of the material and increased contamination. Interestingly, there are no large amounts of corrosive materials on the surface of the plate, only small regions have differed in the neutron attenuation coefficients [26]. Cracks and breaks in the bronze material are visible on the thin section of the plate.

Neutron tomography data was reconstructed from a set of angular projections of the bronze artifact in the form of a three-dimensional (3D) model of the bits (Fig. 3). It can be seen that the artifact represents a collection of several components. The cheekpieces, spiked plates, and snaffle differ in their average attenuation coefficient for the neutron beam and are most likely composed of different materials. Interestingly, the cheekpieces and spikes of the plate are made from quality materials that are characterized by greater durability. It is assumed that these elements serve military purposes, as they provide almost complete control over the rider's part. The relative

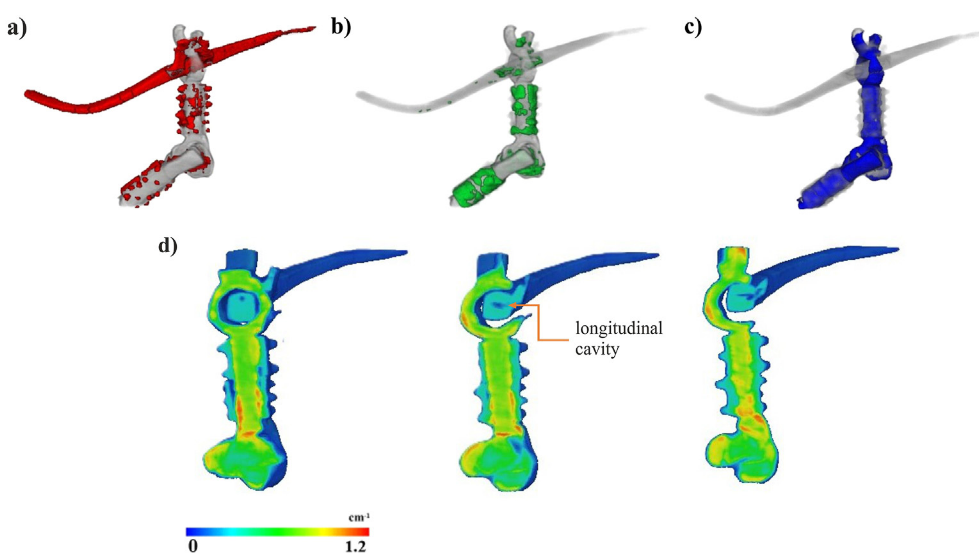

Fig. 3. Reconstructed 3D models and virtual slices (d) of the bit under study according to neutron tomography data, (a) the cheekpieces and spikes of the plate are highlighted in red, (b) the bit plates are highlighted in green, (c) the snaffle is in blue.

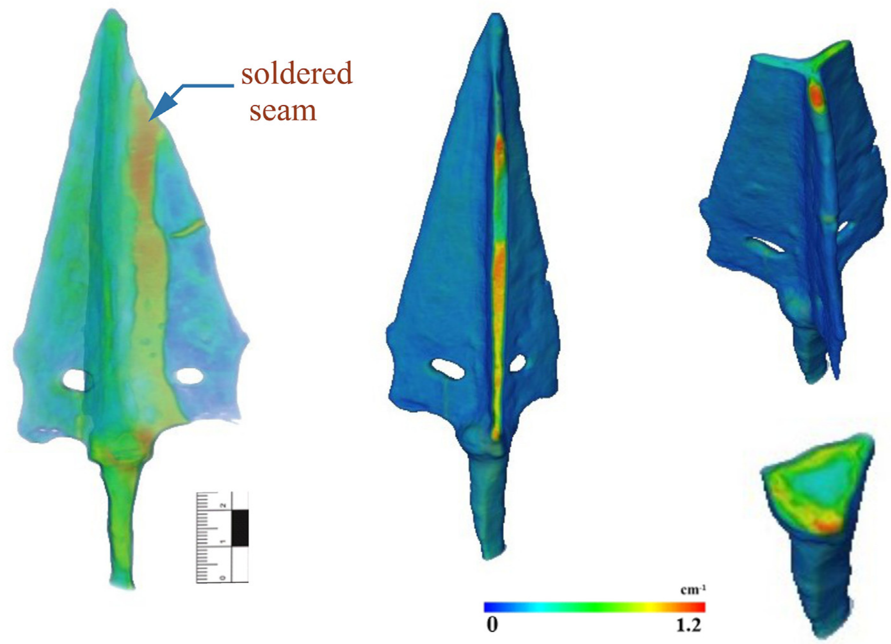

Fig. 4. Three-dimensional model and longitudinal virtual slices of a three-leaf arrowhead based on neutron tomography data. The color scheme reflects the range of attenuation coefficients of the neutron beam in the volume of the arrowhead.

volumes of the components in the bronze bit have been calculated from the neutron tomographic data. The cheekpieces and spikes of the plate occupy 47.56 % of the total bit volume, plates - 37.73 %, and snaffle −14.66 %.

The longitudinal virtual slices of the studied bit are shown in Fig. 3d. It can be seen that the volume of the bit is a bronze product with a spiked plates wrapped around it. Corrosive materials penetrate into the space or joint between the spiked plate and the body of the bit (the snaffle). There is a longitudinal cavity in the upper stick of the bit, which may be the result of defects in the casting of the product [27].

The reconstructed 3D model, as well as several transverse and longitudinal slices of the arrowhead are shown in Fig. 4. On the one of the arrowhead blades, the long structure with a high neutron attenuation coefficient is visible. We believe that area is corresponded to soldering seam, which is the result of the restoration of the object under study.

4. Conclusion

As a result of the study, a three-dimensional model of the metal items in question from the Eleke Sazy memorial complex was reconstructed based on neutron tomography data. Based on this neutron data, the structural features of the arrowhead and bronze bit were identified. Radiographic data of the bronze plate were also studied. From the three-dimensional data, the penetration of corrosion into metal objects of study was highlighted. It is assumed that the bits were made using special technologies characteristic of this population. The obtained data from the site allows us to supplement the information about the ancient population of the region being studied, especially about the culture of the population of the early Turkic period.

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