High Energy Synchrotron Radiation Studies of Tin-Bronze Artifacts from Tell en-Nasbeh, Northern Judah, ca. 1000-586 BCE

E.S. Friedman,[1,2] A. Brody,[3] M.L. Young,[4] D. Peterson,[5] S. Mini[6,7]

[1]Illinois Institute of Technology, Chicago, IL, USA, [2]Consortium for Advanced Radiation Sources, The University of Chicago, Chicago, IL, USA, [3]Badè Museum of Biblical Archaeology, Pacific School of Religion, Berkeley, CA, USA, [4]Northwestern University, Evanston, IL, USA, [5]The University of Chicago, Chicago, IL, USA, [6]Northern Illinois University, DeKalb, IL, USA, [7]Materials Science Division, Argonne National Laboratory, Argonne, IL, USA

Introduction

We developed a program of material science testing on bronze bangles from Tell en-Nasbeh, biblical Mizpah, in order to better understand the acquisition and use of bronze subsequent to the advent of iron in ancient Israel [1]. The eight-acre mound, 9 km northwest of Jerusalem, was excavated from 1926-1935 under the direction of W. F. Badè of Pacific School of Religion. Bronze artifacts were discovered in both an occupation layer and cave burials. The composition of the metal and the manufacturing techniques used to create the bangles inform us of natural resource exploitation, methods of manufacture, trade networks, and perhaps even weight and value systems. Synchrotron radiation based techniques are non-destructive and allow us to examine artifacts without invasive sample preparation. High-energy transmission through 0.5-1 cm thick bronze artifacts provided diffraction patterns and fluorescence data which were supplemented by radiographic and CT images.

Methods and Materials

Seven bangles were analyzed, weighing from 62g to 248g and ranging from 7.0cm to 12.5cm in diameter. High-energy x-ray diffraction measurements were carried out at the XOR-CAT 1-ID beam line of the Advanced Photon Source, Argonne National Laboratory. Complete Debye-Scherrer diffraction rings from each phase present in the diffraction volume were recorded using an image plate (Mar345) with a 345mm diameter, operating in full mode and providing 100 micron pixel size with 16 bit dynamic range. An ion chamber and a PIN diode (p-type, intrinsic, n-type diode) embedded within the beam stop were used to measure the initial and transmitted intensity. With a bent double-laue Si (111) monochromator, the 1-ID beamline provided the high-energy photons (~80keV) and flux ($1x10^{12}$ photons-per-second) needed to penetrate the metal. Using a ceria standard, data were collected from the bangles' mid-section at 90 seconds per measurement in a scan of 1 mm intervals using a beamsize of 100x100μ□. An energy-dispersive detector was added for fluorescence measurements.

Results

The two diffraction patterns represent possible cooling processes and different cooling rates. Bangle 2216b displays fine rings and small grains (fig. 1), which suggests faster cooling. Bangle 2224a shows coarse rings and larger grains (fig. 2), suggesting slower cooling. Alternatively, the differences may indicate that #2216b was more heavily worked than #2224a; annealing could have produced the small grains in #2216b. The grains are on the order of tens to hundreds of microns in size and randomly distributed. The phases present are predominantly Cu (pink rings) and Cu/$Cu_{41}Sn$ (brown rings) from the bulk, with faint CuO_2 from the exterior corrosion layers. The XRF measurements were near-surface (20μ□ and incorporated some surface oxidation but nevertheless, show consistently, an elemental composition of, in decreasing order: Cu, Sn, and Ag.

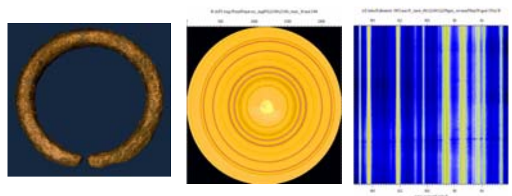

Fig. 1, Sample 2216b (10cm dia., 129.05gr)

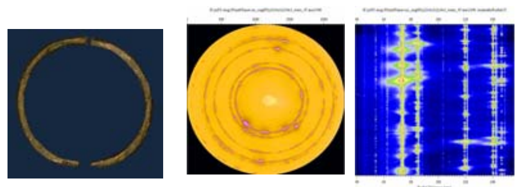

Fig. 2, Sample 2224a (7.5cm dia, 61.97gr)

Discussion

The presence of tin in a copper alloy containing silver but no arsenic strongly suggests a non-local origin, implying that the tin-bronze may have been imported as a bulk material, perhaps in ingot form. Rod ingots in particular would lend themselves to transport and for cutting into pieces for circlets, rings, bracelets and anklets. The cut sections of the rod could then be formed into rings of various sizes and weights. Grain size and texture provide insight into how the bangles were manufactured: i.e., relative rate of cooling and degree of hammering. The random distribution of the grains suggests that the metal was not rolled from sheet metal. Rather, after being cast into molds, the ingots were cut and the metal was lightly hammered and annealed to produce its final shape. Although the objects range in size and weight and may have had different uses, they were all manufactured from the same basic alloy. However, they may have undergone slightly different manufacturing processes. Whether the difference in manufacturing is related to the primary function of the bangles remains to be determined.

Acknowledgements

Jon Almer, Advanced Photon Source, ANL; Alan Green and Charles Hartley, "The Making of Eurasia Project", Dept. of Anthropology, The University of Chicago and ANL. ChemMatCARS Sector 15 is principally supported by the NSF/DOE under grant number CHE0087817. The APS is supported by the U.S. DOE, Basic Energy Sciences, Office of Science, under Contract No. W-31-109-Eng-38.

Endnote

[1] See J.R. Zorn, http://www.arts.cornell.edu/jrz3/index.htm