Synchrotron x-ray diffraction and imaging of ancient Chinese bronzes: some questions waiting to be answered

YOUNG M. L.[1], CASADIO F.[2], SCHNEPP S.[2], MARVIN J.[1], DUNAND D.C.[1], ALMER J.[3], FEZZAA K.[3], LEE W.-K.[3] and D.R. HAEFFNER[3]

[1]Northwestern University, Evanston, IL, 60208, [2]The Art Institute of Chicago, Chicago, IL, 60603, [3]Argonne National Laboratory, Argonne, IL, 60439

Starting in the late 1960s, the study of early Chinese metallurgy, both from a scientific and archaeological perspective, has grown at an impressive pace. The collection of the Art Institute of Chicago comprises approximately 50 bronzes of outstanding artistic quality.
The aim of this work was to test the ability of a range of synchrotron radiation (SR) x-ray techniques to answer specific art-historical questions in a non-destructive way. In particular, we apply both diffraction and imaging techniques using high-energy x-rays (E = 80 keV). Such x-rays can penetrate several millimeters into bronze alloys containing several percent lead, and thus allow us to non-destructively interrogate bulk structures previously inaccessible with surface-sensitive techniques such as typical (lower-energy) laboratory x-ray sources. In addition, the high brilliance of synchrotron x-rays permits use of small beams for diffraction studies, as well as use of phase-enhanced imaging for higher contrast than traditional x-ray absorption methods. We have investigated fragments of a Chou dynasty vessel (*Hu,* 112-255 B.C.), which offer the unprecedented opportunity to compare compositional results obtained with traditional metallographic and SEM/EDX examination of cross sections with non destructive SR x-ray diffraction on whole fragments. We show that the transition from oxidation layers (patina) to bulk microstructure at the edge of the fragments can be mapped with approximately 20 μm resolution. We have also investigated a Tripod Food Cauldron (*Ding*, 8th century B.C), non-destructively characterizing the metal composition, smooth and compact patina and core material contained in the foot. The latter was studied non-destructively using x-ray absorption and diffraction and compared with a destructively-cored piece of material. We have then focused on the inscription inside the vessel. Sometimes used by scholars to glean the history of a particular vessel, inscriptions are of paramount importance and in this particular case the style and content of the inscription had generated some debate as to whether it had been cast or carved. Combining x-ray diffraction data taken in proximity to and inside the characters (to evidence possible residual strain) with phase-contrast imaging allowed for a more complete picture of the processing. Finally, we examined a bronze Dagger Axe (*Ge*, 3rd/2nd century B.C.) with a silver-inlaid casing. The silhouette of the axe had been thought to be the casing placed over a weapon rather than the weapon itself due to the absence of a sharp tip. We have used diffraction to determine the spatial distribution of the composition and the probable processing method used to create the silver inlay. In addition, phase-contrast x-ray imaging provided a detailed view of the interior structure of the axe.

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