Nondestructive Metallurgical Analysis of Astrolabes by Utilizing Synchrotron Radiation

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Introduction

The most sophisticated instruments of pre-telescopic astronomy, astrolabes were born out of man's curiosity about the night sky and methodical mapping of the movement of stars. The astrolabe could be used to solve many problems. It was used as a timepiece to tell time during both the day and night, a surveying tool to measure distances and make more accurate maps, and a practical tool for all sorts of astronomical calculations.

Astrolabes represent the state of the art in materials, design, and forming processes during their time of manufacture. As such, astrolabes are also a valuable instrument to study metallurgy and to learn about the technological history of man.

Because of the intricate engraving that astrolabes have and important historical place they hold, they are highly desired by private collectors and museums alike. Historically, metallurgical analysis has been a destructive process requiring samples to be cut from the artifact, polished, and etched to reveal their microstructure and forming history. It follows that there was very little metallurgical analysis of astrolabes performed in the past [1], since collectors and curators do not want to have the instruments in their collections degraded in any manner.

One technique that is rare in the field of archaeometallurgy is the use of high energy x-rays produced by a synchrotron. It is possible to perform diffraction experiments that give information about microstructure without damaging the object. It is also possible to obtain data on the chemical composition of the sample without requiring a sacrificial sample, as in emission spectroscopy experiments. Thus, studying rare and valuable astrolabes via synchrotron experiments allows analysis of the metallurgy of the astrolabes without causing any damage to them [2]. The astrolabes studied here are two by Georg Hartmann of Nuremberg dated AD 1532 (W-272) and AD 1540 (M-22) and one by Muhammad of Lahore dated AD 1647/8 (A-70).

Methods and Materials

Three main types of experiments were performed.

1. X-ray diffraction experiments: It is possible to determine the mechanical working history of the sample by the nature of its x-ray diffraction pattern. It is also possible to gain information about the bulk composition of the sample from the radial location of the rings in the x-ray diffraction pattern [3, 4].
2. X-ray fluorescence analysis: The near surface composition of the sample can be obtained by measuring the secondary x-rays generated by the impinging x-ray beam [5]. This was performed to determine alloy compositions used for each astrolabe component.
3. X-ray thickness profiles: The transmitted intensity of the impinging x-ray beam is related to the thickness of the sample. Thus, by measuring the transmitted intensity, it is possible to determine the variation in thickness of the sample. By measuring thickness profiles, information about the sample's forming history can be found.

Results

As an example of this analysis methodology, two examples are given: the examination of astrolabe A-70's mater and M-22's rule. Figure 1 illustrates a diffraction pattern taken from astrolabe A-70's mater. The diffraction rings have a spotty nature, indicating that the microstructure of the mater is relatively large-grained. Also, the intensity around the rings shows no systematic maxima and thus no preferred texture. This pattern is representative of the patterns from the maters of Hartmann astrolabes M-22 and W-272.

The chemical composition of the A-70 mater from its fluorescence spectra contains Cu, Zn, Pb, Sn, Sb, Ag, and Fe. The presence of Cu and Zn is expected. Sn and Pb were often added to cast alloys of the time to increase their castability. Sb is a tramp element often associated with Sn, while Fe and Ag are in trace quantities. From these data, we conclude that the A-70 mater was cast with a leaded brass/bronze alloy.

Figure 2 is a diffraction pattern from astrolabe M-22's rule. The spottiness present in Fig. 1 is gone, and very uniform rings are present. The bulk composition of the rule as calculated from the position of the diffraction rings gives a zinc content of 27 wt%. This is at the higher range of cementation brasses manufactured in the Middle Ages.

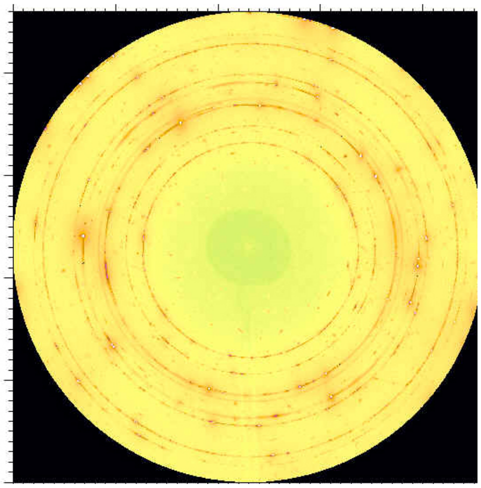

FIG. 1. Diffraction pattern from A-70 mater.

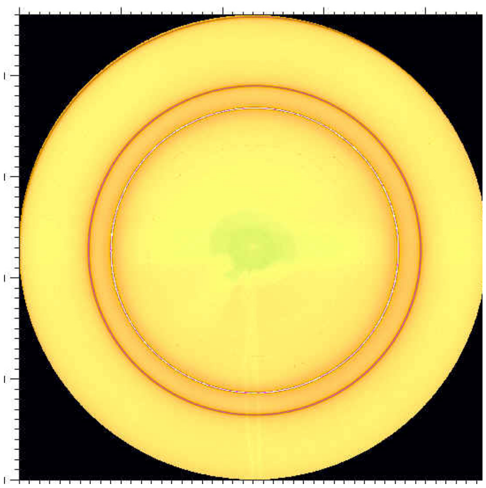

FIG. 2. Diffraction pattern from M-22 rule.

When the surface composition of the M-22 rule was examined by fluorescence, it was seen that only Cu and Zn are present.

Figure 3 illustrates a thickness trace along the length of the M-22 rule. The thickness is nonuniform. The region from x = 0 to x = -3 is a hole around which the rule pivots.

Discussion

The diffraction pattern seen in Fig. 1 is characteristic of a large-grained cast brass. The spottiness is caused by the relatively smaller number of grains sampled when compared to the diffraction pattern seen in Fig. 2. The rule examined in Fig. 2 was formed from hammered sheet brass. The diffraction pattern is representative of the other

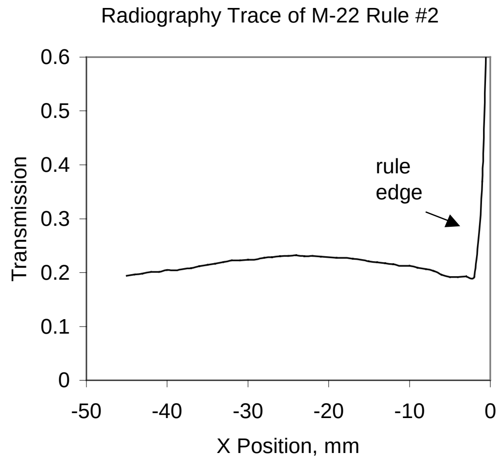

FIG. 3. Thickness trace of M-22 rule.

sheet-formed components of astrolabes W-272, M-22, and A-70. From the calculated lattice parameter, the zinc composition was found to be 27 wt%. From the fluorescence analysis, it was found that the cast mater from A-70 contained additions of Pb and Sn, while the rule from M-22 was a pure brass. For components that must be heavily deformed, a purer brass is much preferred. This pure brass has increased workability because of its low work hardening. The thickness trace shown in Fig. 3 shows that the thickness of the M-22 rule is not constant, which is consistent with a hand-formed component. These trends are representative of results found in all three astrolabes studied. It can then be seen that in the time period of manufacture of these astrolabes, separate brass alloys were utilized for casting and mechanical working applications.

Chemical composition, forming history, and thickness measurements are all determined nondestructively, illustrating that this technique could be useful for many applications with metal artifact analysis where nonintrusive methods are required.

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