

Non-Destructive Metallurgical Analysis of Astrolabes Utilizing Synchrotron Radiation

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Figure 1 – Georg Hartmann astrolabe W272 from AD 1532.

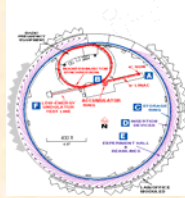


Figure 2a – Schematic of APS synchrotron illustrating storage ring (circumference 1.1 km) and beamline experiment locations.

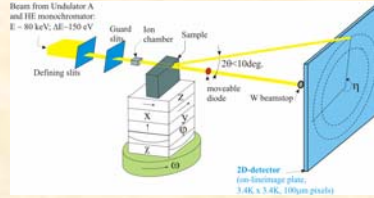


Figure 2b – Beamline closeup of diffraction experiment setup

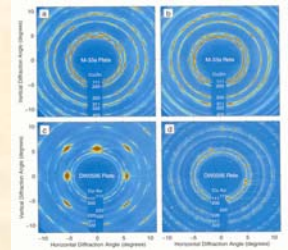


Figure 3 – a, b) diffraction patterns from hand hammered brass astrolabe components; c) pattern from rolled brass and d) cast astrolabe components.

Introduction

The most sophisticated instruments of pre-telescopic astronomy, astrolabes were born out of Man's curiosity with the night sky and methodical mapping of the stars movement. The astrolabe (Figure 1) was a tool that could be used to solve many problems from telling time from the position of the stars/Sun to determining distances and heights of objects as a surveying tool. Astrolabes represent the state of the art in materials, design, and forming processes during their time of manufacture in the Middle Ages. As such, astrolabes are also valuable instruments to study metallurgically to learn about the technological history of Man. In this study three astrolabes have been examined from the collection of the Adler Planetarium and Astronomy Museum: two by the Nuremberg Germany maker Georg Hartmann dated AD 1532 (accession # W272) and AD 1540 (accession # M22), and one from the Lahore Pakistan maker Diya al-Din Muhammad dated AD 1647/8 (accession # A70).

Procedure and Results

Due to the astrolabe's inherent value to collectors and museums, non-destructive analysis techniques are strongly preferred to study the forming history. The synchrotron provides a highly collimated beam of high energy X-rays which can transmit through the brass astrolabes (up to 1 cm thick) and give information about the astrolabe's microstructure. Figure 2a gives an overview of the synchrotron's layout; high energy X-rays are generated by relativistic electrons traveling around the storage ring. The X-rays are then channeled down the beam lines to the experimental stations.

Diffraction Experiments

By placing an area detector behind the sample it is possible to collect transmitted diffraction patterns as seen in Figure 2b. Ring patterns are generated in randomly oriented polycrystalline samples which give information about the microstructure and forming history of the sample. Figure 3 illustrates sample diffraction patterns from a previous astrolabe study [1]. Figure 3a and 3b illustrate patterns from hand hammered brass astrolabe components, characterized by the well defined diffraction rings with randomly oriented maxima. Figure 3c shows very well defined diffraction spots, characteristic of the rolling deformation process. Rolling had not been developed for components of this scale during the time of astrolabe production; therefore, the component must have been made in a later time period. Figure 3d shows diffraction rings that are spotty, which is characteristic of a large grained cast material.

Figure 4 is a diffraction pattern from astrolabe A70's mater. The spottiness of the pattern and location of the rings suggests that the mater was made by brass casting. This component is relatively thick (1 cm) and thus would be relatively easily formed by casting. Figure 5 is the diffraction pattern from astrolabe M22's rule. The well defined rings are evidence of highly worked small grain brass. This component is a thin (1 mm) sheet, which at the time of manufacture would have been made by hammering a rough cast plate ingot to the desired sheet thickness [2].

The lattice parameter of the sample can also be measured from the radial location of the diffraction rings. From Vegard's Law, which states that the lattice parameter of a material changes linearly with the addition of a second element, the bulk composition can be determined from this measurement [3]. Figures 6 and 7 show the compositions of selected cast and hammered components, respectively, as calculated from the {111} and {200} diffraction circles. In a perfect sample and diffraction pattern these two values would be exact, however deviations occur due to the degree of spottiness of the rings. The results are within compositional ranges of cementation brasses of the time [4].

Fluorescence Analysis

A germanium solid state X-ray detector was oriented 45° from the sample face to collect X-ray spectra giving the near surface composition of the astrolabe components. Figures 8 and 9 are the spectra for the A70 mater and M22 rule, respectively. The hammered rule is a pure brass while the cast mater contains Pb, Sn, and Sb additions to increase the castability. It was found that for all three astrolabes these additions were present for cast components while hammered components were a purer brass.

Radiography

The transmitted beam intensity was measured with a photodiode (seen in Figure 2b) as the astrolabe component was moved relative to the beam to give thickness profiles. Figures 10 and 11 illustrate these results for the M22 mater and one of the A70 tympanes. The local variations in transmitted intensity correlate to engraving lines in the samples while the longer range thickness variation is a result of the hand hammering (A70 tympanes) or casting and finishing (M22 mater) of the components.

Conclusion

Valuable data can be obtained completely non-destructively from metal artifacts utilizing the synchrotron. In this study, it was found that three astrolabes showed evidence of casting and hand hammering as forming techniques. Different alloys were used in the cast and hammered components. None of the components from these astrolabes studied were proven to be replacements.

Citations

- [1] Stephenson, G.B., B. Stephenson, and D.R. Haeffner. "Investigations of Astrolabe Metallurgy Using Synchrotron Radiation." *MRS Bulletin*, Volume 26, No. 1, January 2001, pp. 19-23.
- [2] Sisco, A. and C.S. Smith. *Lazarus Ercker's Treatise on Ores and Assaying*. The University of Chicago Press, Chicago, IL, 1951, pp.254-272.
- [3] Vegard, L. and H. Schjelderup. "Constitution of Mixed Crystals." *Physik. Z.*, vol. 18, 1917, p. 93-6.
- [4] Craddock, P. T. *Early Metal Mining and Production*. Edinburgh University Press, Edinburgh, 1995, pp. 292-302.

Acknowledgements

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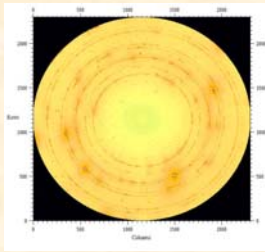


Figure 4 – Diffraction pattern of astrolabe A70 mater

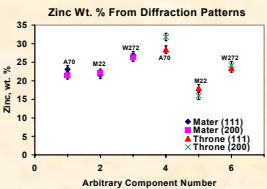


Figure 6 – Zinc compositions of selected astrolabe components. Balance composition is assumed to be copper.

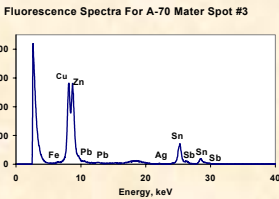


Figure 8 – Fluorescence spectra for astrolabe A70's mater

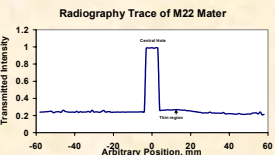


Figure 10 – M22 mater thickness profile as indicated by transmitted intensity.

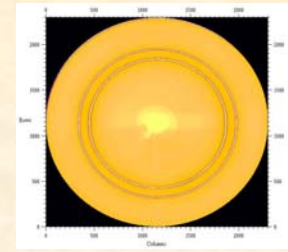


Figure 5 – Diffraction pattern from astrolabe M22's rule

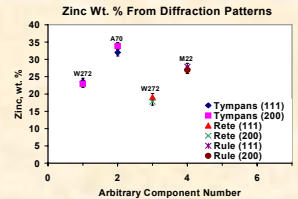


Figure 7 – Zinc compositions from diffraction patterns for Selected hammered components.

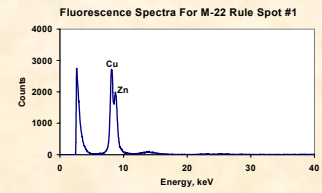


Figure 9 – Fluorescence spectra for astrolabe M22's rule

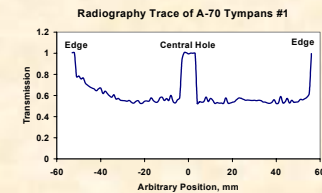


Figure 11 – A70 tympanes thickness profile as indicated by transmitted intensity.

