

Microstructural characterization of European historical swords through neutron imaging

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Abstract

It is evident from several analyses performed on steel samples that the production of arms and armor used cutting edge technology of that time so a study of such artefacts can give fundamental details about the technological skills of a specific area or period. In order to correlate similar samples of a specific age or provenance, it is important to build trustworthy classification parameters. Neutron imaging techniques allow us to determine the morphology and microstructure of composite steel artefacts thus allowing us to characterize the composition, the steel quality, the welds and thermal treatment. We started a systematic study to characterize the production methods of European swords from the early Middle Ages to the 17th century. On this purpose we started analyzing three swords of great importance now belonging to the Bayerisches Nationalmuseum.

White beam tomography allowed detecting the presence of several features in the bulk of the blades as multilayered structures, cracks and defects, and determining the width and the shape of the martensitic hardened edges. Energy selective analysis allowed determining details of the steel composition and microstructure as well as mapping the different low and high carbon areas.

The analysed samples

Hunting sword, produced by **Melchart Diefstetter (bladesmith), Munich, c. 1550 (blade)**, c. 1585 (grip), made of steel, wood, mother of pearl, bone, leather. Inv. no. W 579. From the collections of the House of Wittelsbach. Only the lower part of this sword blade has been sharpened on both sides. It is likely that this 'long knife' was used for hunting.

W 579



Sword, produced in **Northern Italy, possibly Milan, c. 1560**, made of steel (partly gilt and silvered), enamel. Inv. no. W 587. From the Kunstkammer of the margraves of Brandenburg-Ansbach. This majestic sword is considered to be one of the **most important objects ever to have been produced by an Italian weaponsmith.**

W 587



Longsword, produced in **Tyrol in the late 15th century**, made of steel (partly gilt), enamel, leather. Inv. no. W 872. From Ambras Castle, Innsbruck. This sword is generally considered to be one of the **most beautiful medieval swords in existence today.**

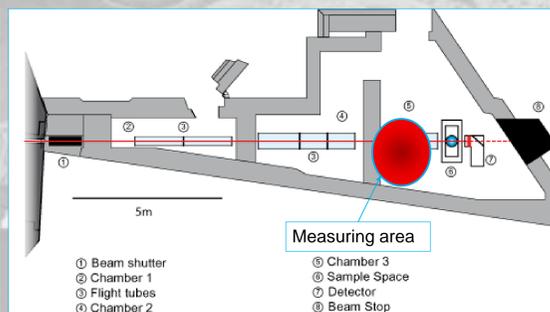
W 872



Instrumentation used for analysis

ANTARES at Heinz Maier Leibnitz, TUM, Munich

Using midi (150x150 mm field of view, 120 micron resolution, 75 micron pixel size) configuration



The aim of the experiment was the measurement of the blade internal structures and the identification of morphological features as welding areas, quenched volumes etc...

To protect the surface of the whole swords, it was wrapped in aluminium foil. The blade part was inserted in an aluminium solid tube to connect to the rotating stage. Since the handle of the swords contained gold and silver, in order to protect such a part from activation, elastobore borated rubber was wrapped around to prevent irradiation.

Tomography parameters:

#Projections: 1120

#Tomo per sample: 4/5

#Open beam images: 10

#Dark field images: 10

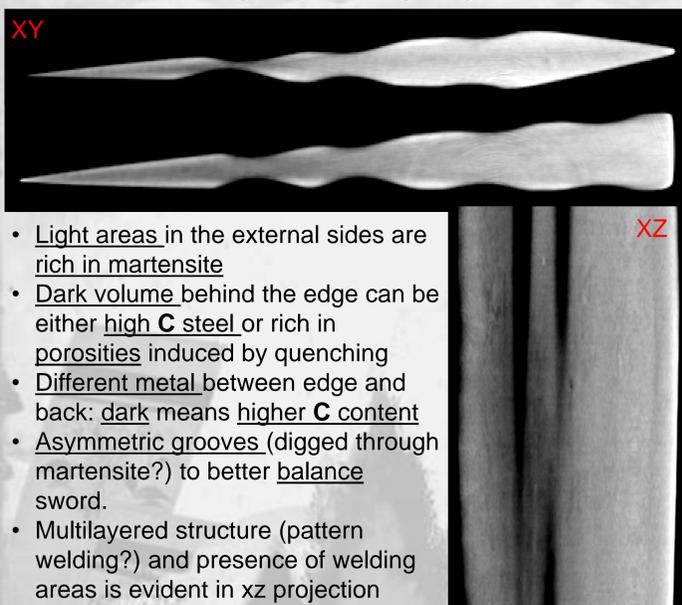
Reconstruction software:

ImageJ / OCTOPUS

Neutron tomography results

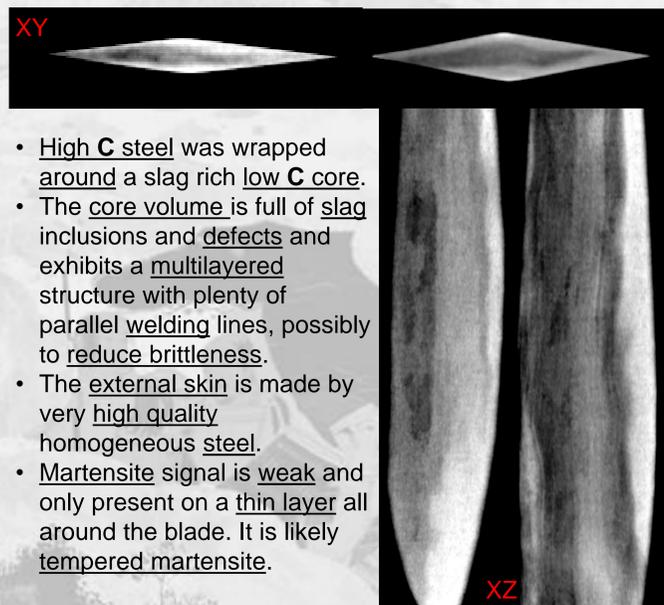
White beam tomography allowed to detect the presence and shape of several morphological features in the bulk of the blades as multilayered structures, cracks, defects, and to determine the width and the shape of the martensitic hardened edges.

W 579: double edged tip area, single edge rest of the blade



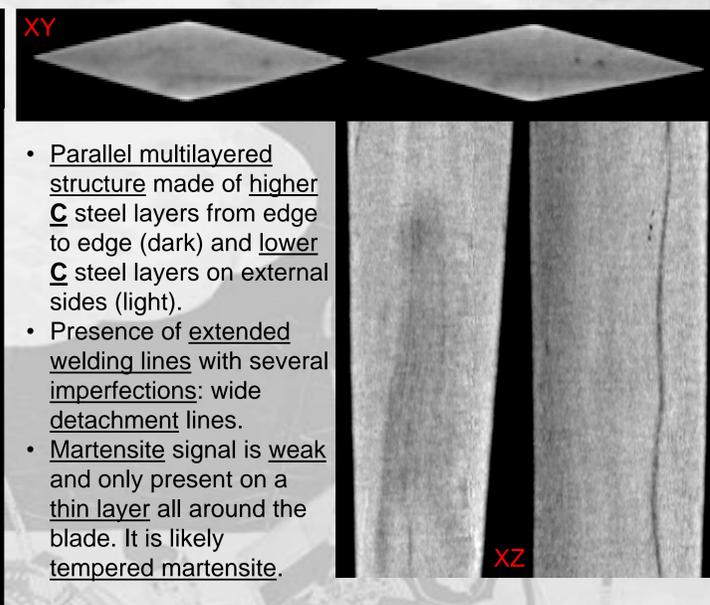
- Light areas in the external sides are rich in martensite
- Dark volume behind the edge can be either high C steel or rich in porosities induced by quenching
- Different metal between edge and back: dark means higher C content
- Asymmetric grooves (dugged through martensite?) to better balance sword.
- Multilayered structure (pattern welding?) and presence of welding areas is evident in xz projection

W 587: double edged sword with rhomb section



- High C steel was wrapped around a slag rich low C core.
- The core volume is full of slag inclusions and defects and exhibits a multilayered structure with plenty of parallel welding lines, possibly to reduce brittleness.
- The external skin is made by very high quality homogeneous steel.
- Martensite signal is weak and only present on a thin layer all around the blade. It is likely tempered martensite.

W 872: double edged sword with rhomb section.



- Parallel multilayered structure made of higher C steel layers from edge to edge (dark) and lower C steel layers on external sides (light).
- Presence of extended welding lines with several imperfections: wide detachment lines.
- Martensite signal is weak and only present on a thin layer all around the blade. It is likely tempered martensite.

Conclusions

- Neutron tomography provided high quality volume reconstruction showing important morphological details which permit to characterize the microstructural unique features of the swords
- The application of the method to European late Middle Ages / early Renaissance swords allowed to answer specific questions:
 - The assembly method and phase distribution of the different types of steel and the spatial distribution of inclusions and defects.
 - The presence and extension of quenched martensite rich areas.
 - The mapping of the spatial distribution of welding areas and an overview of their quality.