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Radiographic and Tomographic Inspection of Wooden Specimens with Fission Neutrons

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Abstract

Wood is one of the eldest crafting and building materials as proven by remnants in many archaeological excavations. Particularly in subjects of cultural heritage radiographic technologies are the appropriate non-destructive methods to gain insight without dissembling or even touching the specimen. X-rays or gamma radiation may be the appropriate tools, except in cases of any metal shielding or encapsulation that makes any wooden structure inaccessible to X-ray inspection.

This problem has been resolved by applying neutrons for radiography and tomography. Since neutrons are prone to scattering, they need a certain minimum velocity passing straight through the sample volume. A beam-line complying with these requirements is available in the form of fission neutrons at the nuclear research reactor of the Technische Universität München in Garching/Munich (FRM II, NECTAR). The example of a wooden specimen partly shielded with a thick metal plate shows no impairment in visualising the detailed structures by the shielding in the reconstructed images of a neutron tomography.

Keywords: NDT of wood, water and resin distribution, metal shielding, neutron radiography of voluminous specimens of high hydrogen content

Background

It is proven that wood is the first material mankind ever has used in the course of civilisation. Even the *Homo erectus*, an ancestral relative who lived some 400 thousand years ago, was hunting with wooden spears in central Europe[1]. From prehistoric times up to the industrial revolution, wood was also the primary fuel, rather essential in the cold times after the last glacial period some 60 thousand years ago. Supposedly, wood was as important as the flint stone in the Stone Ages. However, since stone and ceramics are much more durable materials than wood they have been found preferably as remnants documenting the prehistoric human life. On the other hand, there is no defined period in any age that deserves to be characterised as something like a „wood age" since this material has been indispensable at all times both, as a raw material for multiple purposes and as fuel – until the upcoming of coal, which in turn is a derivative of wood, though after a tremendously long processing time. The way how wood has become an essential material throughout the development of mankind is sketched in Figure 1. It starts with the properties (top left) which make it to such a universal material but also entails the reason why it may perish in a long run. It is combustible so it serves as a fuel on one hand, but makes wooden artefacts or buildings prone to destruction by fire. It floats on water (with a very few exceptions) so large logs can be easily transported across far distances as rafts on rivers and lakes without the need of a vehicle. Finally – as a biological material, it is inherently structured with heterogeneous patterns and is principally subjected to biological degradation if infested with certain organisms and exposed to oxygen.

Since any biological decomposition needs water the internal moisture is a key parameter in any aspects of wood protection and preservation. Particularly humidity contributes to the growth of various kinds of mould destroying cellulose. Some of them are even able to digest lignin, one of the most stable natural polymers. When adhesives have been introduced, some certain glue formed an ideal growing matrix for bacteria – causing another problem in the stability in case of glued parts.

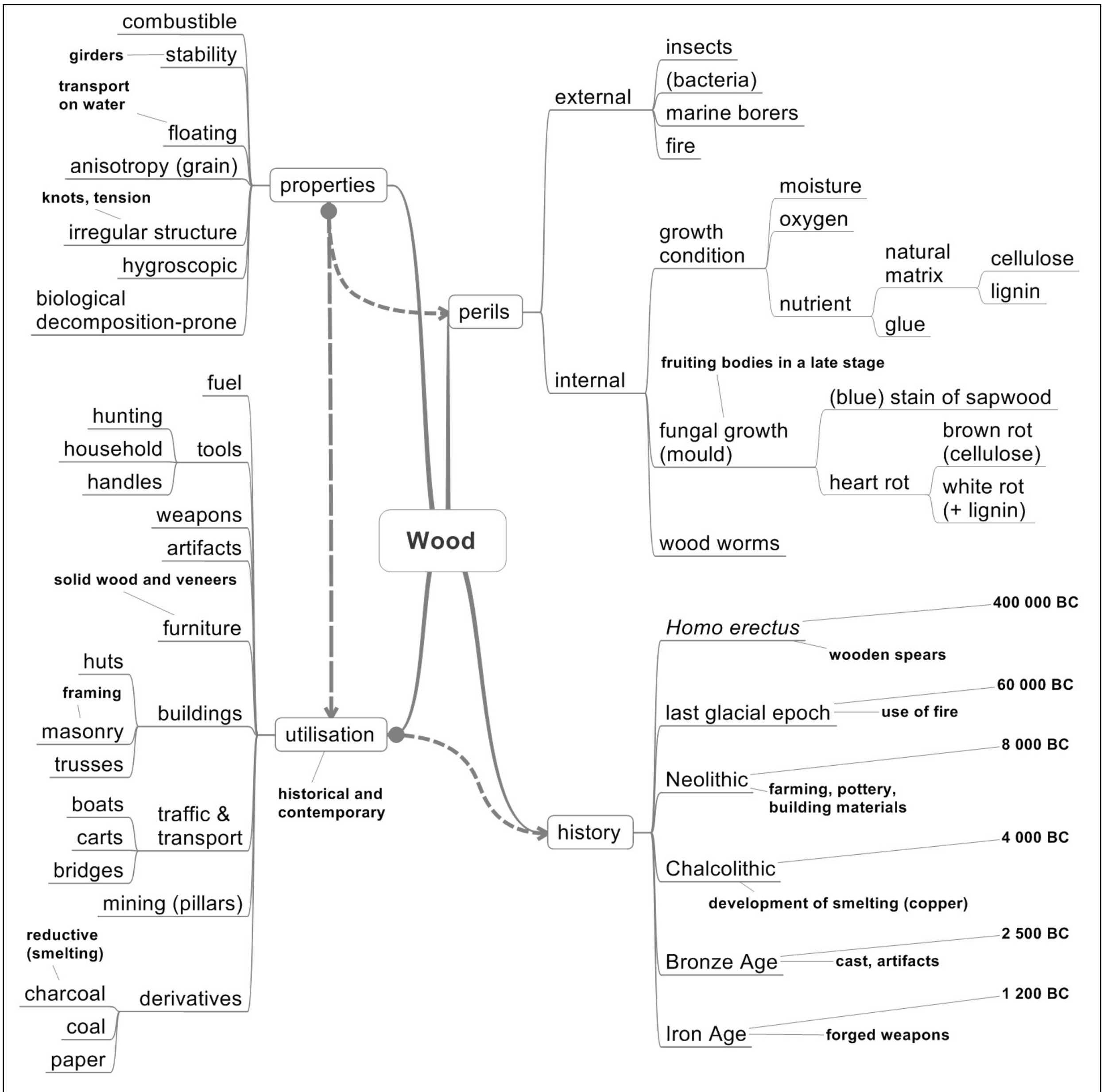

Figure 1. Properties of wood making its central role as the timeless material of mankind

Wood has found its way into multiple applications of our life like no other material, particularly when including its derivatives such as charcoal for metal smelting, coal for the steel production and, last not least, paper. So it was this material that paved the way of cultural development from the early hunters using wooden spears, dwellers of cold areas warming at a fire place up to the daily newspapers of nowadays.

Why neutrons?

The usual way of radiographic inspection is using X-rays or gamma radiation, particularly when examining metal parts. By this way, flaws such as cracks or cavities become easily visible particularly in the homogeneous environment of e.g. a metal plate. So there is no obvious reason not to subject wood to the same testing procedure. As a matter of fact, this has been done with success[2]. However, wood is structured in a way which makes the detection of cracks and other irregularities more difficult than in homogeneous man-made materials. Moreover, the relevancy of a crack e.g. in a wooden girder could be less serious than in another one made of steel. As mentioned before, the presence of moisture would be of greater concern since the growth of mould could easily impair the mechanical stability of a wooden beam by more than three quarters without any sign of damage from the outside. Principally, it could be a worthwhile application of neutron radiography to investigate the spatial distribution of moisture; exact quantification is currently under development.

Another challenge for radiographic inspection appears with the presence of shielding by metal objects. This is rather frequently encountered when excavating archaeological artefacts where wooden parts in the core may be surrounded by metal sleeves. This could make any radiographic study using X-rays or gamma radiation impossible, unless the metal parts will be removed what may be rather undesired with precious specimens. In this case, neutron radiography is capable to overcome this obstacle and to provide an appropriate solution since metals are transparent to neutrons. However, there is a restriction for larger wooden specimens due to the moderation effect of hydrogen. They need to possess sufficient energy to penetrate thicker layers. In practice, thermal neutrons are not suitable for radiography in such cases. It is necessary to have fast ones such as fission neutrons without moderation by water in the range of 1 to 2 MeV as they are available at the NECTAR (Neutron CT and Radiography) facility within the research neutron source "Heinz Maier-Leibnitz (FRM II)" of the Technische Universität München in Garching/Munich.

The object

As a model case, a piece of square shaped timber with a rotten edge, some worm and nail holes and prepared with two small pieces of wax stuffed into holes from the outside (Figure 1) was placed in the beam line of the reactor together with a steel plate as a shielding. This would make a complete X-ray radiograph or a tomography impossible particularly in the perpendicular direction to the plate, in difference to the neutron technology as shown here.

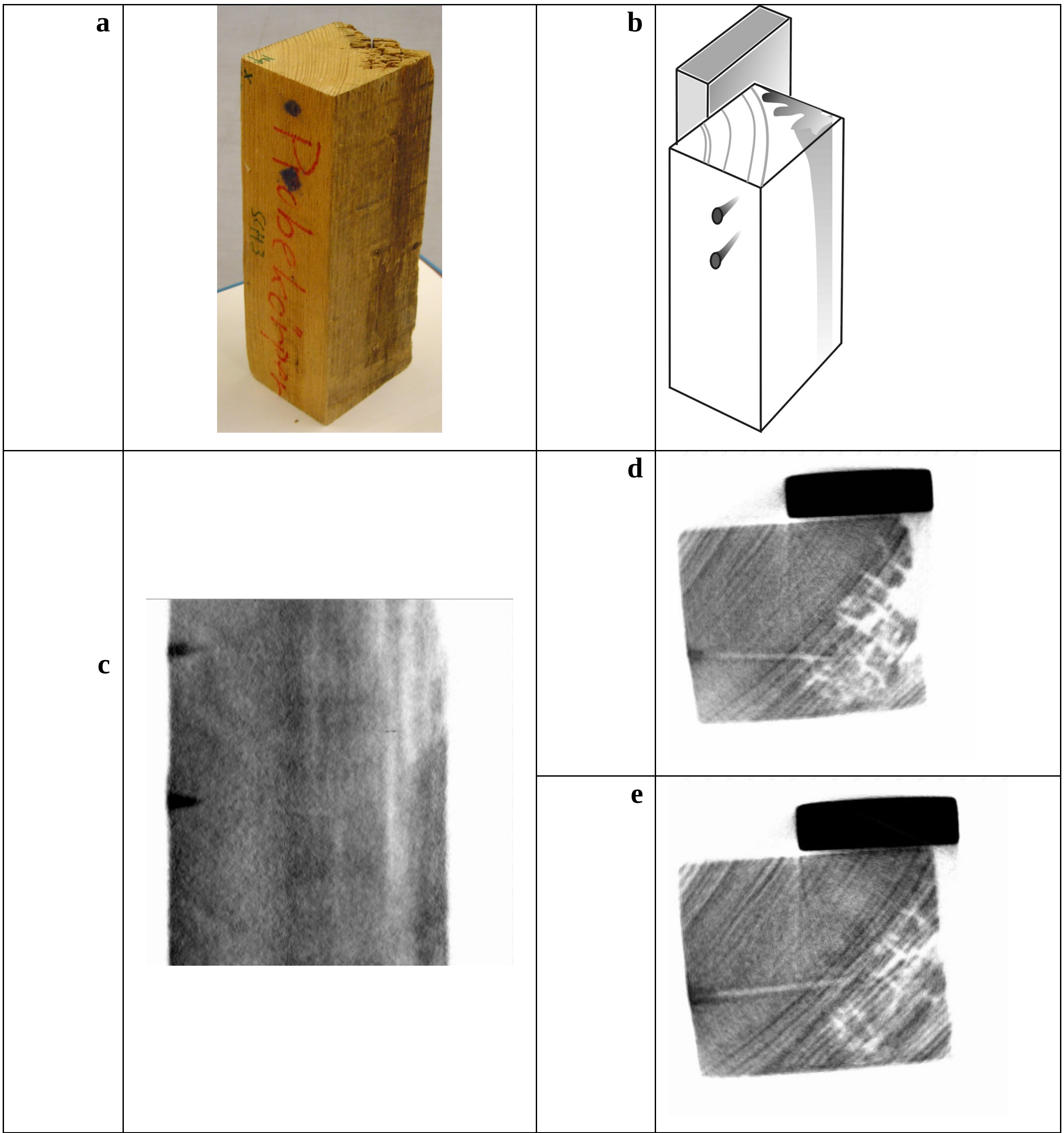

Figure 2: Tomography of a square shaped timber with flaws and inclusions
a) specimen with the two inclusions (dark), **b)** sketch of positioning with steel shielding,
c) vertical section with the two inclusions on the left and damages on the right,
d) section through the upper inclusion with steel plate, annual rings and damaged area,
e) section through the lower inclusion with the same details.

The resulting tomographic reconstruction (Figure 2) showed the rotten area in detail in spite of the presence of the heavy metal shield. Such an image without disturbing shadows can be achieved with X-rays only without the adjacent steel plate. Remarkably, the two small wax inclusions appear rather prominently in the reconstructed images due to their higher hydrogen density as compared to the surrounding wood matrix. However, the X-ray technology is capable to produce images of much higher quality due to principal differences. First of all, neutrons are more prone to scatter than photons. Secondly, experimental neutron beams cannot compete with photonic ones due to the complex generation technology, i.e. no strictly allocatable focus, in addition to the scattering behaviour. A particular problem with fast neutrons is to convert them in a suitable detector array for imaging without the need of rather thick moderators that may spoil any image by lateral scatter. The development of improved image converters with a reasonable efficiency is in progress.

Conclusion

While X-ray technologies provide already a commonly available tool to gain insight into the internal structure of wooden specimens, neutrons might be a complementary tool to investigate differences in hydrogen densities, i.e. material differences. They definitely permit an inspection whenever a wooden core is shielded by heavy metals and dismantling is undesired as in archaeological or cultural artefacts. In such cases, neutron radiography and tomography are the only tools to achieve access to the inside.

References

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