Study of internal structure of natural cork: X-Ray or T-Ray

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ABSTRACT

Natural cork is of immense importance to the wine industry because of its structure and chemical properties. These corks are grown naturally and because of its special cellular structure, it inherit some properties suitable for using as a wine bottle sealant. Natural corks are not permeable to fluids, it is very elastic but not easily breakable, also its buoyancy is very high. All these characteristics make it a perfect solution for wine bottle stopper. So, wine industry has very high demand of natural corks. It is very important to distinguish between good quality and bad quality corks. Both X-Rays and T-Rays have been used to study the internal structure of natural corks. In this short review article, a comparison of both technologies have been discussed.

Keywords: Cork defect; Defect; Internal structure; Natural Cork; Non-destructive testing; Terahertz; X-Ray.

Introduction

Although non-destructive testing with terahertz imaging has been successfully applied in many areas but very few scientists has shown its use to study the internal structure of natural cork. X-Rays has been used to study the internal structure of natural cork. Quercus suber, also known as cork oak, is the primary source of natural cork, widely available in southwest of Europe and northwest of Africa. Portugal, alone is the largest exporter of natural cork and cork production and its export around the world drives its economy. Amorim cork, based on Portugal, is the world's largest cork production company, which supplies almost more than 50% of the corks worldwide. Natural cork is used as a wine bottle stopper. Normally wine bottles are kept for several years before it hits the supermarket self and if these corks, used as a bottle sealant are not of optimum quality, oxygen can diffuse through the cork into the wine converting wine into vinegar, a great loss for the billion dollar wine industry. Here it comes the importance for the wine industry to use only top grade natural corks for its bottle sealant.

Unarguably, there is a need for gradation of natural corks before it gets packed from the factory and shipped to wine makers. Amorim cork, has several R&D unit for the testing of corks. Readers are requested to visit the official website of Amorim cork (https://www.amorimcork.com/en/) to know more about the production and use of natural cork in the wine industry. Since, the quality of a cork is very important to the wine industry, the cork manufacturing company has to make sure, it supplies the best quality of the cork. Corks are natural product and from the moment it is grown, it develops some natural pores, holes, lenticular channels etc inside and or outside of the cork material. These defects actually helps diffuse oxygen inside the, something not suitable for wine industry. Figure 1, shows three different photographs of three different types of natural corks.

Figure 1(a, left image) is the longitudinal view of a highly defective natural cork with lots of pores, cracks and holes and these type of cork are not preferred by the wine industry. Figure 1(b, centre image) is fairly good quality cork and figure 1 (C, right image) is a cross sectional view of a natural cork with a big lenticular channel and crack at the front, also not suitable for wine bottle stopper. It is also possible that a cork looks near perfect from outside but there may be cracks/defects/lenticular channels inside the cork material not visible through naked human eyes. Naturally, there is need for the cork industry to study the internal structure of natural cork before it is packed for selling.

Evaluation of internal structure of natural cork

Although a defective cork (presence of voids, cracks, lenticels etc) can be easily detected visually if and only if the defects are on the outside surface of the cork and this method is the only prime procedure to distinguish cork quality through visual inspection but it does not guarantee to spot a cork which is visually defect free and full of defects inside. It has been observed that a cork which is visually defect free from outside but has cracks/defects once the cork is cut through longitudinally, *i.e.* presence of internal defects. The only way to determine those defects is to reconstruct its internal structure by very popular tomographic method (Michela Antonelli, 2005, G.T.Herman, 1995, Wei Sun, 2017, Jun B, 2005, Teiko, 1996, S Yoshizawa, 2006, B. Recur, 2011, D. M. Koller, 2011, S. Wang, 2003, M. Bessou, 2012). Tomographic reconstruction method is not new and it is being used very successfully in medical sciences, pharmaceutical industry, steel and metallurgy industry, security industry etc. The most popular technique is X-Ray computed tomography, although not safe to use for human or any living organism because of its ionizing capability but until now it is the most viable method to use to generate reconstructive image of internal structure of any object because it penetrates most of the objects without much deviation or loss of its energy.

X-Ray computed tomography/micro-computed tomography has also been used to study the internal structure of natural cork, to determine any hidden defects inside it. Vanda Oliveira *et all* studied the internal structure of natural cork by X-Ray micro-tomography (Oliveira Vanda, 2016). The authors followed the usual procedure to acquire data for their tomographic measurement. 2D slices of data was taken and was stacked them to get the 3D image of the cork samples. In this measurement, the authors used absorption measurement data for tomographic slice reconstruction. The authors also used image analysis and image segmentation as a post-processing tool to improve the final image quality. Figure (2) shows the reconstructed image of natural cork by X-Ray micro-tomography with very high resolution images (Oliveira Vanda, 2016). From the reconstructed image, the defects inside or on the surface of the cork is clearly visible.

T-Ray was also used to investigate the internal structure of natural cork quite successfully. Hor *et all* studied the non-destructive evaluation of natural cork sample by terahertz imaging (Hor Yew Li, 2008). The authors studied different cork samples and from their results, the defects are clearly visible from the THz reconstructed images.

Mukherjee *et all* generated 3D images of natural cork to evaluate its internal structure (Federici, 2011, Suman Mukherjee, 2013). The authors used radon transformation and back-projection algorithm to generate 3D images of the natural cork using T-Ray absorption data. From the reconstructed images, the defects inside the cork is clearly visible. Figure 3, shows the 3D reconstructed images of natural corks with defects inside them. These defects are not visible from outside by human eyes but THz sees through the cork structure and help us identifying those defects (Federici, 2011).

These defects are clearly visible from these tomographic images. In this case, transmission data was collected and the authors did measurement of absorption for the purpose of the reconstructed image generation of natural corks. The black portion of the above images is defect free and white regions have some kind of defects in it. Although one can spot defect inside those cork sample but it is not clear from those images to distinguish what type of defect it is. Although Mukherjee *et all* developed an algorithm to eliminate some artefacts arises due to THz tomographic imaging but a lot of work needed to be done in this area to get a near perfect T-Ray tomographic image (Suman Mukherjee, 2013). We are still far from a perfect THz-CT image, especially of an object with fairly high refractive index (1.1-1.7).

Conclusion

It is very important to have a very robust testing arrangement for the investigation of the internal structure of natural cork right at the factory production unit. Several tomographic methods have been tested successfully. In this article, the tomographic images of corks have been shown, tested by both X-Rays and T-Rays. X-Rays are better to identify smaller defects and lenticular channels. On the other hand, T-Rays can detect voids, cracks, lenticels etc of any sizes inside cork but fails to identify the shape and or size of the defect. Readers are suggested to read some of the original articles mentioned in the references section to understand it better. Having said that, we still need some better algorithm to implement T-Ray tomographic technique to investigate those defects inside natural corks. Because of the low wavelength and high energy, X-Rays are not appropriate to detect very tiny of defects. T-Rays could be a better choice, if one can eliminate all the artefacts arises due to Fresnel's reflection and other natural optical phenomena. Terahertz could be a better choice for investigating the internal structure of natural cork (R.I: 1.1-1.2) sample, as THz is more susceptible to attenuation for slight change in internal structure of the cork or non-uniformity in its structure. Another drawback with T-Ray is its slow detection rate. Because of its slow detection rate, it is not suitable to implement in the factory unit, where thousands of corks needed to be inspected every day. In this area, X-Ray wins the race and again it is not a perfect solution and the reason has been mentioned above.

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(a) (b) (C)

Figure 1(a): Longitudinal view of a highly defective natural cork (Left). **(b):** Longitudinal view of a good quality natural cork (Middle). **(C):** Cross-sectional or radial view of a defective natural cork with lenticular channel (Right).

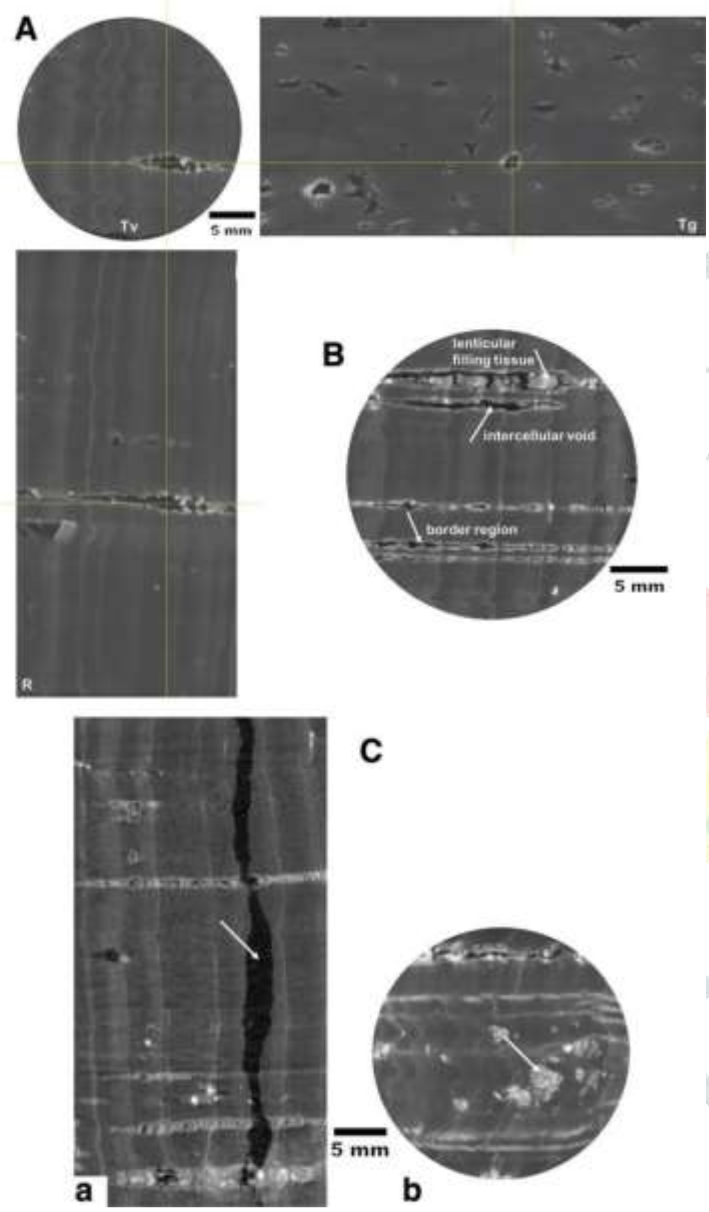

Figure 2: (A): 2D reconstructed slice of a natural cork (resolution 50 micro-meter). T_V: Transverse section. T_g: Tangential section. R: Radial section. The crossing point of the two lines represents same point on the cork. **(B):** 2D slice of a transverse image. **(C):** Defects in cork. (a): Empty ant gallery. **(b):** "nail" lignocellulose inclusion. Image taken from (Oliveira Vanda, 2016).

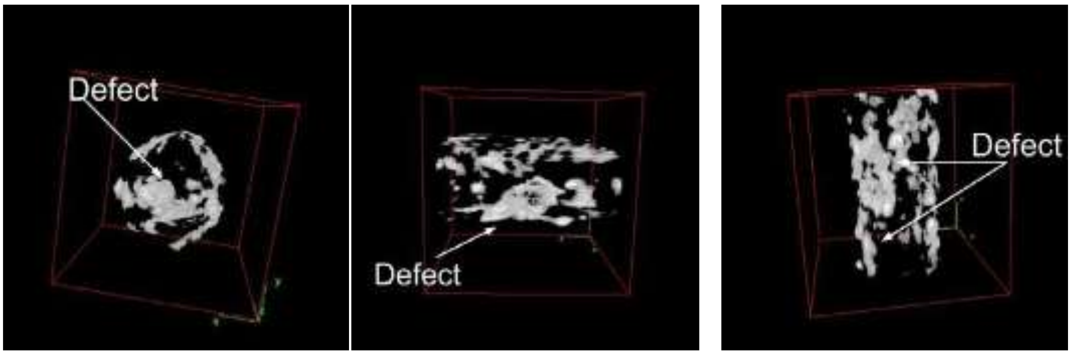

Figure 3: 3D tomographic images of natural corks having internal defects by THz imaging. The images are at different orientations. Images taken from (Federici, 2011)