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Lockin thermography for defect characterization in veneered wood

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Abstract

The technique of lockin thermography combines the advantages of both conventional thermal wave methods and thermography using a commercial IR-camera. It allows for shorter imaging time and depth profiling. Inhomogenenous illumination and optical surface structures can be suppressed in phase images. Several examples show applicability of lockin thermography to detect and locate hidden flaws in layered material.

1. Introduction

Wood is of considerable interest for industrial applications ranging from building construction to furniture. With respect to natural resources, real wood is mostly used only as an outer layer ("veneer") with some kind of cheaper material (e.g. chipboard) underneath. It is one major goal of quality control to detect areas of poor adhesion as early as possibly in the manufacturing process in order to have a fast feedback to the production parameters. Such an inspection should provide \an image in a reasonable time to locate faults. Conventional nondestructive inspections based on x-rays or ultrasonics do not perform well in this case.

Photothermal detection is sensitive to boundaries [1]. However, a point-by-point raster image is too slow at the low modulation frequencies required to detect substrate structures under the veneer. Fast thermal depth probing at low modulation frequencies is feasible with phase-sensitive modulation thermography ("lockin thermography") where the local phase shift of the thermal response is analyzed. The phase shift depends on the kind of boundary underneath and hence on debonding.

2. Arrangement for Lockin-thermography

Various techniques have been developed to obtain information in a short time [2, 3]. Lockin thermography has obviously the following advantages: A large depth range can be obtained due to low modulation frequencies. Phase and magnitude imaging time is much shorter than with usual photothermal measurements [4, 5]. Measurements
minutes. Thermal wave sources are simple and cost efficient. One can use different kinds of sources (e.g. modulated optical beam from a lamp or warm air from a heat gun) to generate thermal waves in the material. The sample surface does not need to be painted black in order to improve the optical absorption, since for a white surface the thermal wave excitation can still be done well using modulated warm air. Another important advantage compared to flash excitation is low power density. For the industrial application of this technique it is essential that no overheating occurs and that one can avoid to blacken the surface of the wood.

Fig 1 shows the general setup of lockin thermography. A PC-system with A/D-D/A interface synchronizes the thermal wave source and image sequence recording.

3. Applications

Veneered wood is a layered material where the detection of boundaries or subsurface structures is of interest. The first test for depth range and defect size was performed on a sample provided with holes with of various diameters in the substrate.

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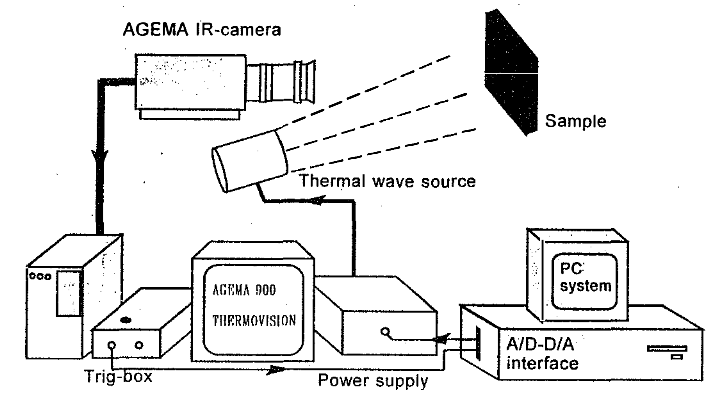

Fig 1 Experimental setup for lockin thermography

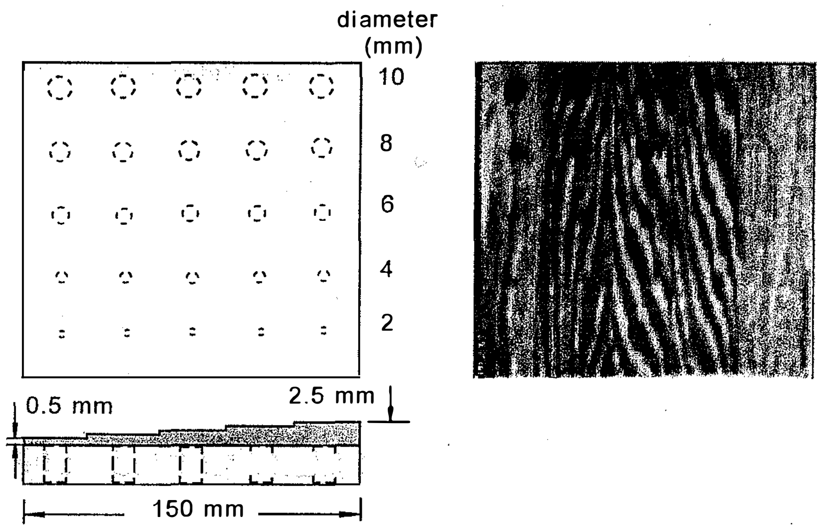

Fig. 2 Sample geometry and phase image taken at 0.03 Hz

Veneer thickness ranges stepwise from 0.5 mm to 2.5 mm. The phase image taken at 0.03 Hz shows the matrix of subsurface defects clearly (fig. 2). The holes can still be revealed if veneer thickness is less than 2 mm. This depth range is good enough for most industrial applications. Holes with less than 4 mm diameter can not be found, since during manufacture of the sample some glue material was left in them.

Another test was performed to investigate the disclosure of material imbedded between the veneer (0.5 mm) and the substrate. The sample geometry of imbedded materials (teflon film and an Al-film each with 50 μm thickness) together with a knot in the substrate wood is shown in Fig 3. In addition the substrate was provided with holes to allow for comparison of signal structure.

As a result, the phase images taken at 0.03 Hz, 0.06 Hz and 0.12 Hz show the substrate holes and knot structure. The teflon film in the middle of sample can not be detected since thermal diffusivities of wood, teflon film, and plastic veneer used in this case are quite similar. It is noticeable that the phase contrast of the Al-film depends on frequency, its sign is just opposite at 0.03 Hz and 0.12 Hz. At 0.06 Hz the Al-film structure disappears in the phase image. This

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behavior can be explained with a two-layer model where an Al-film with 50 μm thickness is located underneath a surface layer of 0.5 mm (fig 4a). The phase contrast as a function of normalized thickness d/μ is plotted in fig 4b where μ is thermal diffusion length and d is surface layer thickness. The sign of phase contrast reversion can be proved in the theoretical curve.

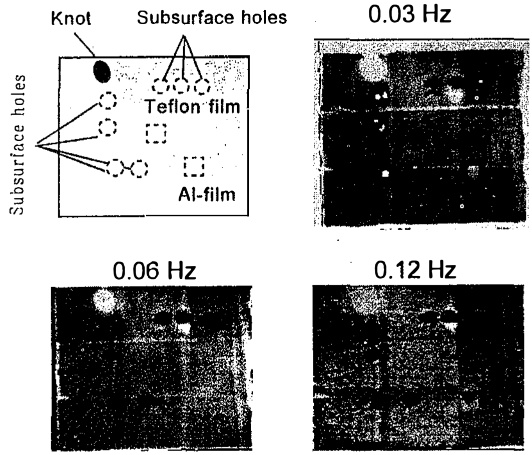
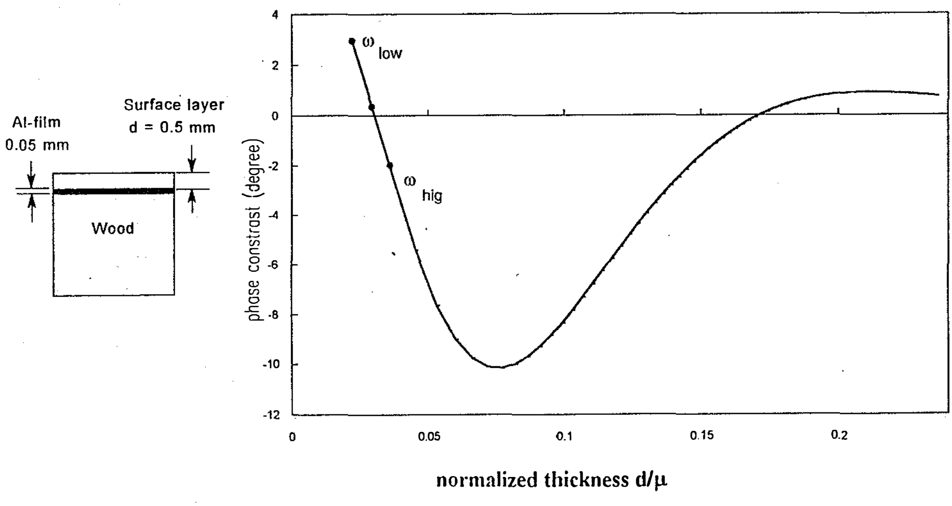


Fig. 3: Phase images of a sample with imbedded materials at 0.03 Hz, 0.06 Hz and 0.12 Hz (left)

Fig. 4: Two layer model (a) with the phase constrast as a function of normalized thickness (b) (below)



The delamination or adhesion problem of veneered wood can be described in terms of thermal contact resistance. The thermal wave technique is suited as known for the characterization of boundary defects [6]. Fig 5 is the phase image taken at 0.36 Hz which shows veneer stripes and delamination areas clearly.

Delamination can have various reasons. One of them is that the substrate material is not the same everywhere: due to different thermal properties of substrate materials delaminations can arise after some time. Therefore it is important that one can detect substrate differences in the early stage. Fig 6. shows an example where veneer thickness changes stepwise from 0.5 mm to 2.5 mm on maple (left) and oak (right) wood. The phase angle image taken at 0.03 Hz clearly distinguishes between left and right side up to 2mm veneer thickness.

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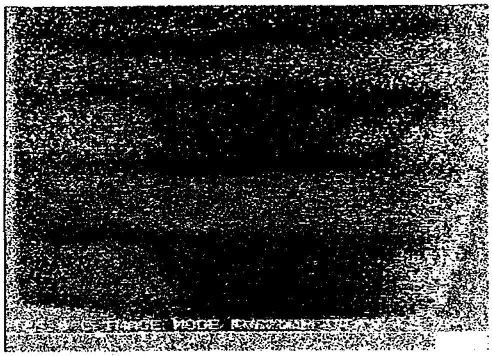

Fig. 5 Detection of delamination of veneered wood

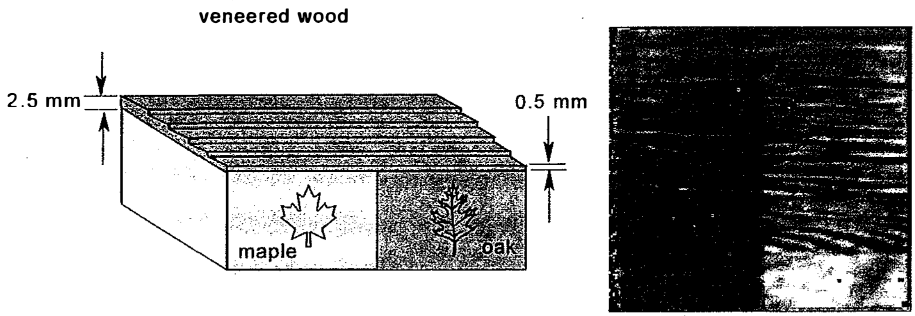

Fig. 6 Surface veneer on different substrate wood

Another potential reason for later failure are knots that are hidden below the veneer. Therefore we investigated how well such a knot oriented along the boundary could be detected (fig. 7). The result is that one third area of phase image shows the substrate knot structure again until about 2 mm underneath the surface layer.

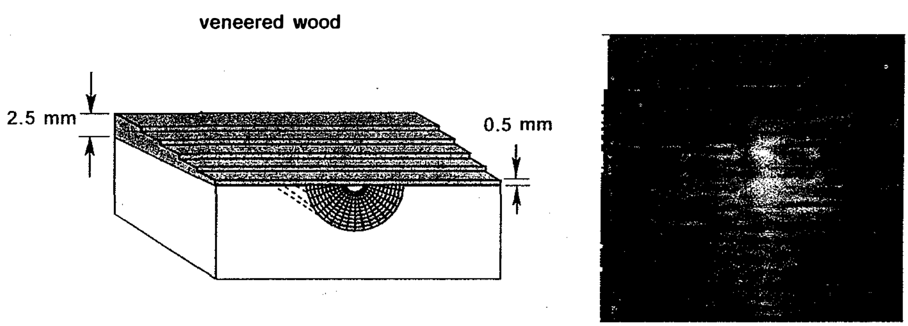

Fig. 7 A knot structure located in the substrate wood under veneer

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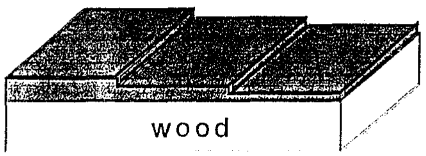
Varnish layers or paint layers are usually deposited on the surface of wood products (furniture) for protection and decoration. Fig 8 is an example of painted wood where the paint layer thickness varies stepwise from 50 μm to 150 μm. In the phase angle image three regions due to different paint layer thickness can be distinguished well. The total phase change at 0.06 Hz is about 4 degrees.



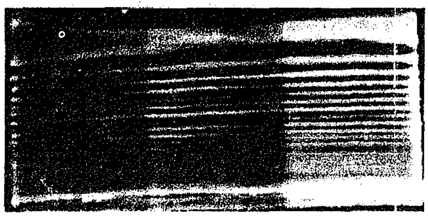


Fig. 8 Paint layer thickness variation on top of sample surface

4. Conclusions

Several examples obtained on veneered wood were presented to demonstrate the applicability of lockin thermography which combines standard thermography and thermal wave technique. It has been found that within about 3 minutes we can obtain an image showing subsurface features hidden under 2 mm thickness veneer. These features can be holes, imbedded material, delamination, knots or the kind of substrate wood. Therefore this technique is of relevance for industrial quality control. Veneered wood is one kind of layered material. Lockin thermography can be used in fact for characterization of various other layered materials for industrial applications.

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