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ACTIVE THERMOGRAPHY AS NON-DESTRUCTIVE TECHNIQUE IN THE DIAGNOSIS OF PATHOLOGICAL MANIFESTATIONS IN WOOD PIECES

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ABSTRACT

This paper aims to present the feasibility of the use of thermography as a non-destructive technique to diagnose the pathological manifestations hidden in wood pieces, whether they come from natural manifestations such as nodes, cracks, chemical, atmospheric and biological or of anthropic agents. Through the use of the active thermography technique, which uses pre-heating of the analyzed surface, experiments were carried out in order to identify the position of natural defects in these pieces. Additionally to this analysis, some holes were produced in order to compare the evolution of the heat on the pieces' surfaces with and without holes. Same sized pieces were used, in order to simulate structural parts present in roofs, beams, etc. The tests were carried out in the laboratory, with temperature and humidity recorded. The results demonstrated the feasibility of using the active thermography technique as a tool for the preliminary diagnosis of occult pathologies near the surface of the wood pieces and their maintenance in initial stages.

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INTRODUCTION

All over the world, wood is a universal, easy to process material used for important infrastructures, but this material may present many degradation cases: moisture and temperature variations affected by local conditions are the principal factors affecting the rate of wood decay. Wood deteriorates more rapidly in warm, humid regions with respect to cool or dry places. Principal organisms degrading wood are fungi, insects, bacteria and marine borers with damages ranging varying from discoloration to complete wear of wood with possible catastrophic consequences such as total breakdown of involved structures, Wyckhuyse and Maldague (2002). The characterization of wood properties is critical for the understanding of material behavior and performance under operating conditions, Ross and Pellerin 1991 apud Bucur (2003). Non-destructive testing (NDT) constitutes an evaluation technique that allows the knowledge of properties of a given material (wood, concrete, soil, etc.) without it being damaged by laboratory tests, NDT Source Center (2012).

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NDT have wide application in areas where there is doubt about the structural integrity of a part, sometimes inaccessible, such as dams, bridges, churches, roofs, etc. The advantage to perform NDT in a structural element is that it is not necessary to take it to the lab and destroy it to know its mechanical properties; the estimation of these properties is made in loco. When dealing with wood it is also possible, with NDT, to verify the integrity in living trees, which brings greater security to society and also avoids unnecessary felling of perfectly healthy trees in parks and urban areas. A combination of several NDT methods for monitoring is generally required to provide reliable results for the characterization of a material, failure detection and determination of geometric parameters. This can lead to the need of information of different scales that are combined, Kurz, J. *et al*., (2012). Among the various sorts of NDT the following local non-destructive testing and global nondestructive testing can be cited: resistance to penetration testing and resistance to perforation testing (local NDT) and ultrasound, acoustic emission, microwave tomography, thermography and x-rays (global NDT), among others. Thermographic analysis is a diagnostic technique based on a NDT, which uses cameras and infrared sensors to measure temperature and heat distribution, in order to detect problems

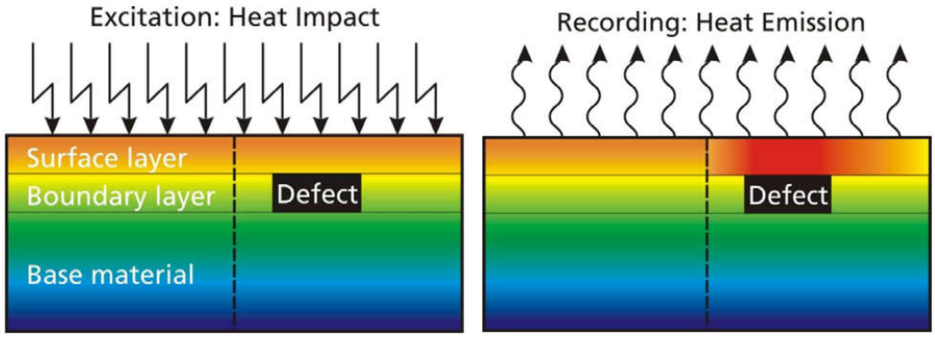

Fig. 1. Principle of infrared thermography, showing the uniformly distributed heat impact on the surface (left), the recorded heat emission (right) and the warmer region (dark) on the surface above the defect, Meinlschmidt (2005)

Fig. 2. Infrared camera used in the experiments, FLIR (2016)

Fig. 3. Nails used (15 x 15). Author's collection

in its initial phase and precisely in the affected area, FLIR (2016). This paper aims to present the tests performed in wooden pieces, which were heated by an external heat source, in order to identify the position of natural defects, using a thermographic camera. Additionally to this analysis, some holes were produced by nails, on all pieces' surfaces, in order to compare the evolution of the heat distribution.

Literature Review

Non-destructive testing (NDT)

According to Bucur (2003), nondestructive evaluation of the physical properties of wood has its origin to solve practical problems without destruction of the integrity of the object under inspection. The earliest nondestructive evaluation of wood was by visual inspection. The development of scientific nondestructive methods became possible in the early 20th century with the development of the theory of elasticity and of the instrumentation for the measurement of wood properties. Enhanced characterization using NDT does allow the potential of timber and even other material and the structures made of it to be determined, would this be for new as well as for old infrastructure. The characterization of wood properties is critical for the understanding of material behavior and performance under operating conditions, Bremer *et al* (2015). The large number of potential methods for nondestructive evaluation of wood requires a sufficient understanding of the different NDT techniques applicable to wood and associated materials, Bucur (2003). Modern production techniques in the wood and wood-based industry reached a high quality standard at high output rates. While the speed of the production machines increases, it is necessary to introduce modern and faster working online inspection methods in order to monitoring the material for defects, Meinlschmidt (2005).

Infrared thermography: According to FLIR (2016), the human eye sees only a small part of all existing radiation. The part a person can see is called visible radiation, or visible spectrum. The visible spectrum goes from the red color, which has less energy, to violet, the most energetic color. Outside this visible spectrum, there are infrared (lower) and ultraviolet (upper), as well as other types such as radio waves, microwaves, x-rays and gamma rays. All living things and objects emit radiation, and this radiation occurs as a function of temperature. The higher the temperature, the greater the amount of radiation. The radiation associated with temperature is called infrared radiation. At high temperatures, from 500ºC, the radiation begins to enter the visible spectrum. Apart from these specific cases, human eye can not see heat. Infrared cameras are capable of detecting radiation and transforming it into an image visible to the human eye. In passive thermography, the objects themselves serve as a source of energy. The camera captures the images according to the temperature difference of these objects with the background. In active thermography, it is necessary to have a source of energy. The emitted energy is reflected by the objects under study and captured by the camera. According to Meinlschmidt (2005), if a material under inspection is heated with an external source, active thermography, the temperature of the surface should rise suddenly. The speed at which the heat font dissipates into the material depends on the thermal properties (density, heat capacity, thermal conductivity, etc). A defect in the sub-surface can create a barrier for the heat diffusion process and, then, the surface temperature above the defect should decrease more slowly than the temperature in other regions. The surface above such defect will show a hot spot for a longer time as its vicinity, Fig. 1. In contrast to the fast dissipation of heat in metallic materials, the dissipation of heat in wood-based-materials is slow. The detection of defects can take a few seconds or even some minutes after the heat impact, depending on the material and the depth of the defects. The presence of a defect, at a certain depth, can interfere with the heat propagation and such interference produces a local surface temperature variation. Generally, a surface defect becomes immediately visible, while a deep defect becomes visible with a certain delay. A large surface defect is associated with a large contrast which is weakened, as the size of the defect decreases or depth increases. The thermal contrast depends on the difference between the thermal conductivity of the material and of the in homogeneity, Meola, Carlomagno and Giorleoapud Spencer, M. (2008). Figueredo *et al*. (2017) also concluded that internal defects allowed the temperature increase on the surface above the defects. According to them, the analysis of the thermograms used as principle the differences on surface temperatures to indicate possible internal pathological manifestations in wood. The hottest sites on the surface indicated areas with some type of internal pathology, while the colder or more homogeneous temperatures represented areas where there was no loss of internal material in the piece. This could be explained by the mechanisms of heat transmission. Being homogeneously heated during the same period of exposure to a heat source, the intact, flawless wood part exhibits homogeneous temperature rise throughout the surface. Otherwise, the heterogeneity of the heating points to the existence of areas of thermal bridges. These are caused by alteration of section, existence of materials with greater capacity of thermal conductivity or some hidden reason.

"The passive heating method has a large field of applications for knot detection, slope of grain, imaging of moisture content distribution, wood rupture phenomena and imaging of cavities in trees. An advantage of passive heating over the active heating procedure is its ability to produce temperature distributions without resorting to mechanical loading of the material. The thermal stress is relatively low and does not damage the material. The disadvantage of the passive method is that the thermal images are transient and require a fast recording system to capture the most interesting images during the test. The most widely used for in situ detection is with an infrared camera, which produces an image of an object through electronic detection of infrared emitted from the object. The development of infrared video cameras has extended the wavelength range of visible light video cameras to a thermal infrared range between 3 and 12 µm", Bucur (2003). According to Cortizo (2007), in order to produce a good image, it is necessary to care about the distance of the camera to the object, in order to reduce the influence of the medium in reading the temperature of the object. Veratti (1992 apud CORTIZO, 2007) says that only when the Instant Field of View (IFOV) is less than or equal to the measured area (extensive source), an accurate temperature measurement can be performed. In practice, it is necessary the IFOV to be at most half of the measured area to minimize the effect of the average measurement of the detector. In the case of point sources, the measured temperature will always be lower than the actual value.

Maldague (2002) affirms that each NDT technique has its own strengths and weaknesses. In the case of infrared thermography, the strengths are as follows:

- Fast inspection rate (up to a few m^2 at a time);
- No contact between parts;
- Security of personnel involved;
- Results are relatively easy to interpret;
- Wide span of applications;
- Unique inspection tool for some inspection tasks.
- On the other hand, there are some difficulties specific to infrared thermography:
- Difficulty in obtaining a quick, uniform and highly energetic thermal stimulation over a large surface;
- Effects of thermal losses (convective, radioactive) which induce spurious contrasts affecting the reliability of the interpretation;
- Cost of the equipment;
- Capability of detecting only defects resulting in a measurable change of the thermal properties (e.g. disbonds and cracks are only detected if they induce interface thermal resistances);
- Ability to inspect a limited thickness of material under the surface (thermography is a 'boundary' technique);
- Emissivity problems.

Experimental Setup

The equipment used to capture the thermographic images in the experiments was FLIR camera, T450sc, resolution of 320 X 240 pixels, with IFOV of 1.36 mrad, minimum focus distance of 0,4 m and ±1°C (±1.8°F) or ±1% of reading for limited temperature range accuracy, Fig. 2. The wood species used was pinus (pinus elliottii) cut from high quality defect-free boards. For samples cut far from the tree center and small in size in relation to the distance to the pith, the growth ring curvature can be ignored and properties are regarded as orthotropic with three orthogonal planes of material symmetry: longitudinal, radial, and tangential. At structural dimensions and for simplicity in modelling, wood is mostly considered transverse isotropic, assuming identical properties in the radial and tangential directions, Bodig (1982). The pieces were, in average values, 21.2 cm long in the parallel to the fibers direction, 7.2 cm long in the radial direction and 2.8 cm long in the tangential direction. Ambient temperature ranged from 25°C to 28°C and 56% relative humidity. The pieces were exposed to heat for 40 minutes, using a halogen lamp, 0.6 m away from the pieces. The camera was used to capture thermal images before, during and after the 40 minutes of heating. While the pieces were still warm, defects were produced on all surfaces, in order to observe the feasibility of the thermography technique as a means of observation for pathological manifestations close to the surfaces of the wood pieces. On the largest lateral faces, 5 nails (15 x 15) were used to produce 1 cm deep holes; on the other two lateral faces 4 nails (15 x 15) were used to produce 1 cm deep holes and at the top and bottom, 2 nails were used to produce 2 cm deep holes, Fig. 3 and Fig. 4.

RESULTS

The pieces' temperatures before heating, during heating and after 40 minutes of heating are shown in Fig. 5. The scale on the right of each image correlates colors and temperatures. In Fig 4b, on the left piece, it is possible to see a knot and, on the right piece, there are inclined cracks.

Both regions kept higher temperatures than their vicinities. Fig.6 shows the cooling process' results, after the 40 minute heating period.

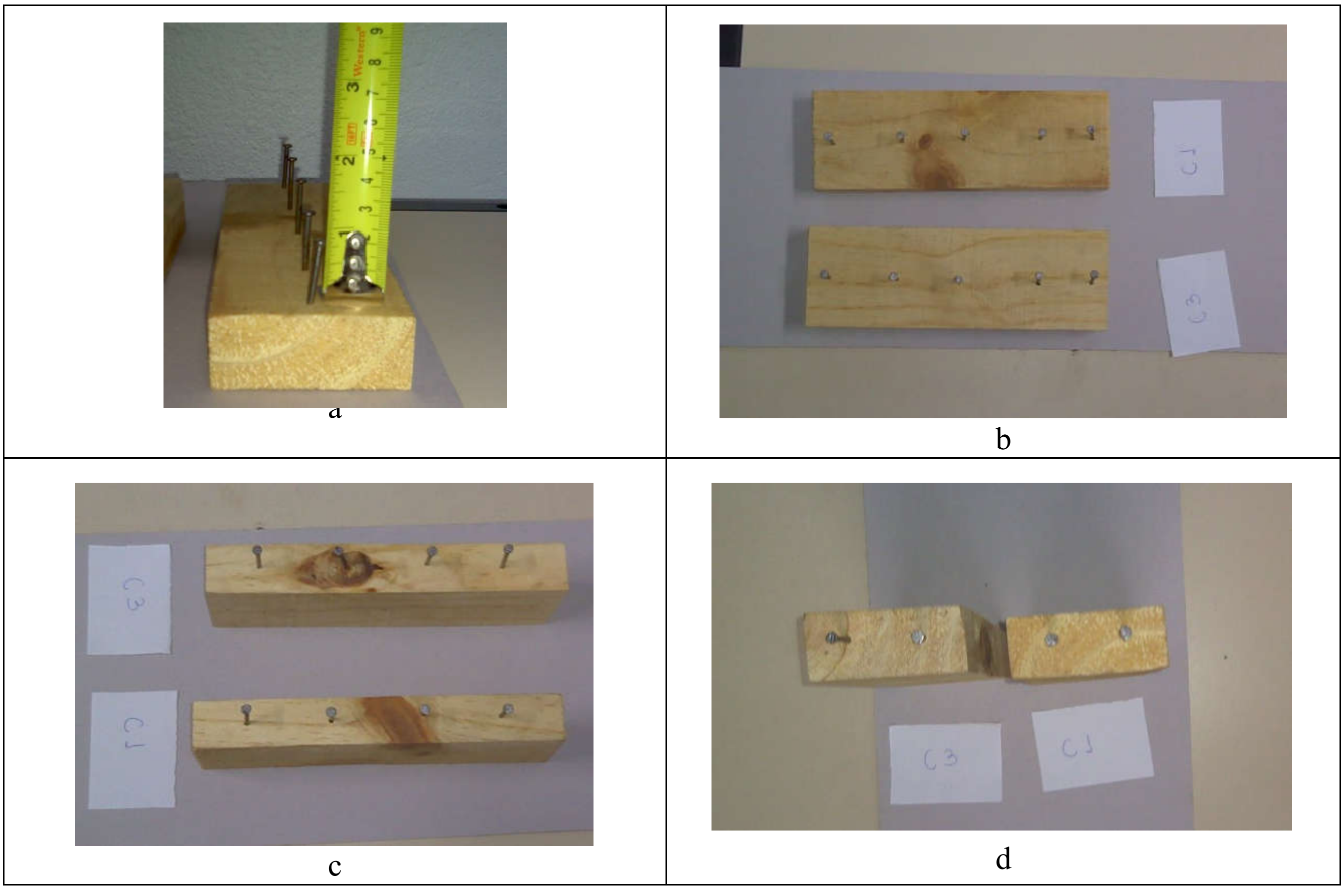

Fig. 4. Holes produced on the surfaces (a) Holes on the largest lateral faces, lateral view; (b) Holes on the largest lateral faces, view from above; (c)Holes on the smallest lateral faces, view from above; (d) Holes on the top and bottom, view from above. Author's collection

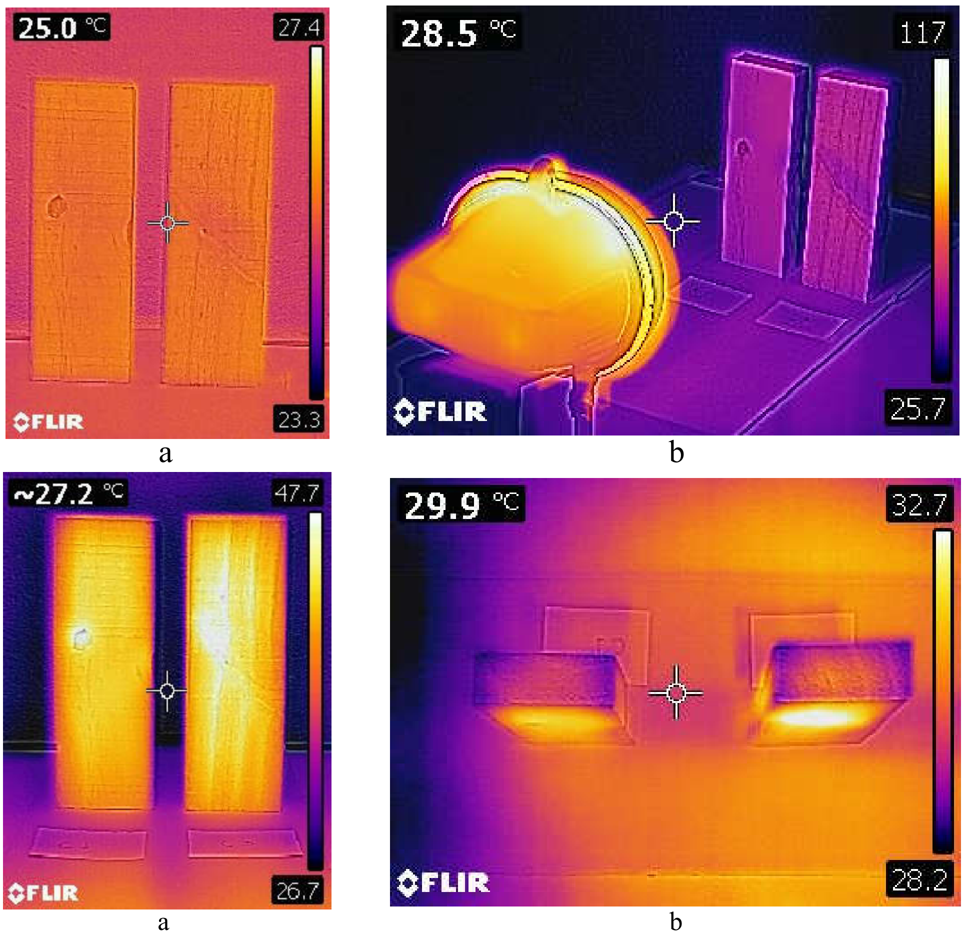

Fig. 5. Heating phases (a) before heating; (b) during heating; (c) after 40 minutes of heating. Author's collection

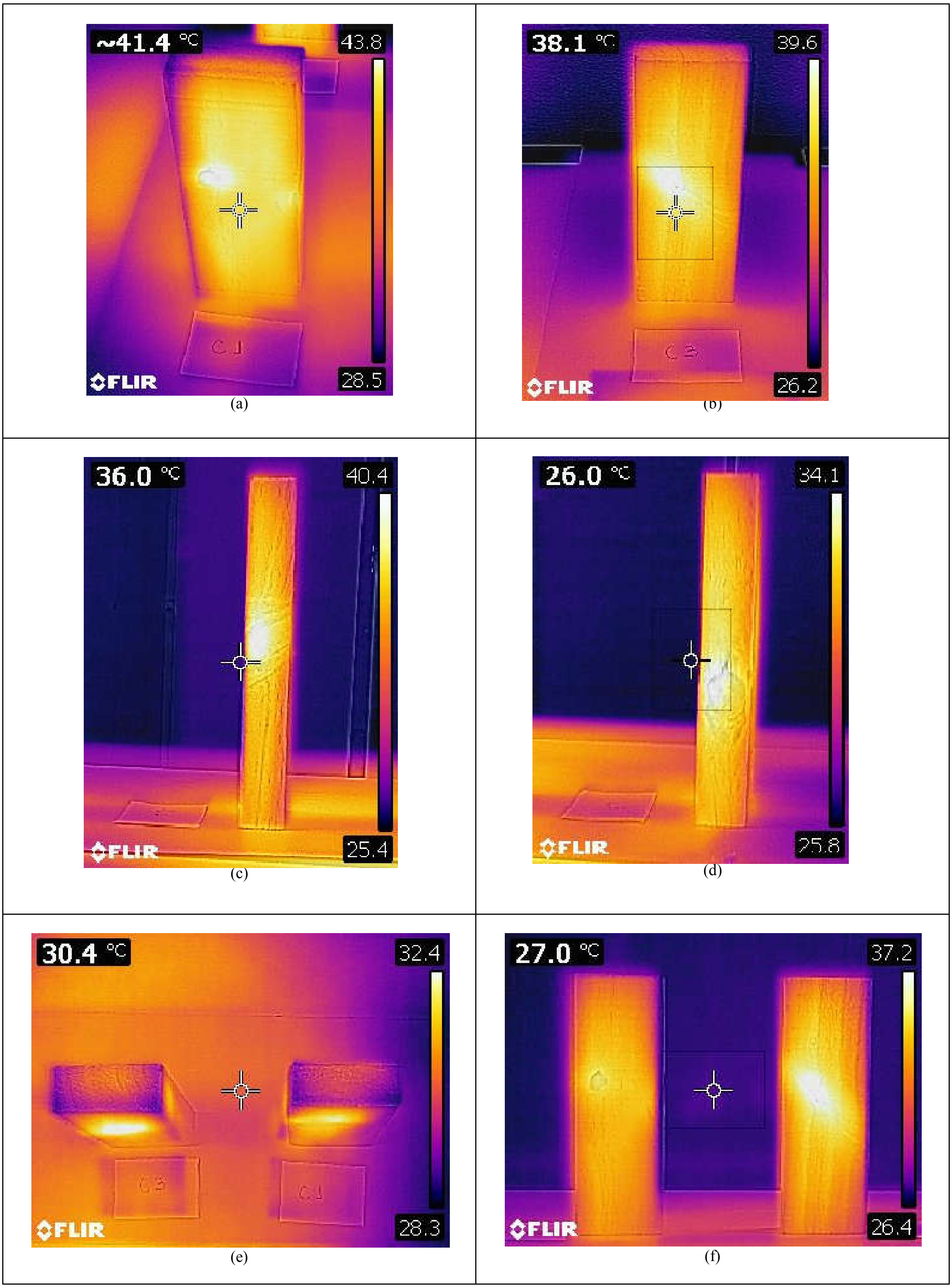

Fig. 6. Cooling process' results, after the 40 minute heating period. Source: Author's collection

As before, both knot and inclined cracks regions kept higher temperatures than their vicinities. Fig.7 shows the cooling process' results of the holed pieces. Both knot and inclined cracks regions kept higher temperatures than their vicinities. The temperatures inside the holes were smaller than the regions next to them. As the holes were produced while the pieces were still warm, the outside surfaces were warmer than the inner layers.

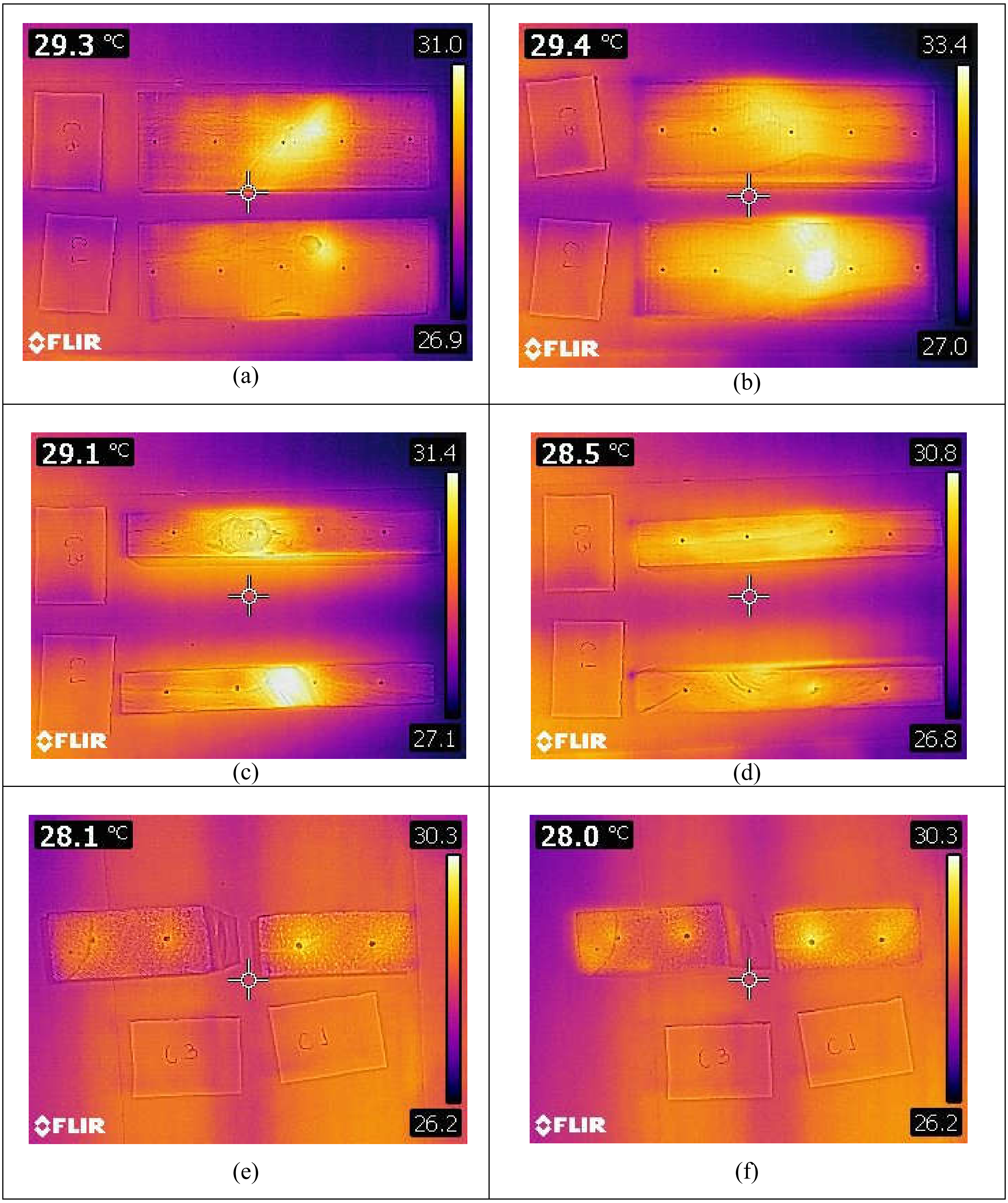

Fig. 7. Cooling process' results of holed pieces. Author's collection

Conclusions and Outlook

The experiments shown in this paper showed similar results obtained by Meinlschmidt (2005), Meola, Carlomagno and Giorleoapud Spencer, M. (2008) and Figueredo *et al*. (2017): the surface temperature above the defects decreased more slowly than the temperature in other regions and the surface above such defects showed a hot spot for a longer time as their vicinities. This occurred during both heating and cooling processes. As the holes were produced while the pieces were still warm, the temperatures inside the holes were smaller than the regions next to them.In future experiments the setup test should be: i) heating the pieces for 40 minutes, ii) cooling process until ambient temperature, iii) preparation of holes, iv) heating process again, v) cooling process again. Thus, it will be possible to compare the possible temperature variation inside the holes and their vicinity. It is also planned to submerge the pieces in water and analyze the heat change during the process. From the tests, it is possible to highlight important points in the application of thermography. Some information is needed so that the results captured by the camera are reliable, because materials with different properties react differently when exposed to heat, just as humidity and ambient temperature also influence the results. In general, it is inferred that the thermography technique proved to be reliable in the identification of defects in pieces of wood and also in the monitoring of the progress or decrease of the heat. These results indicate that these tests can be done in old wooden structures, without a destructive technique, for a preliminary defect location analysis.

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