DEFORMATION OF WOOD VENEER ON AIRCRAFT SANDWICH PANELS ASSESSED BY DIGITAL IMAGE CORRELATION (DIC) AS AFFECTED BY A FIRE RETARDANT TREATMENT

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Abstract

Business aircraft furniture is made with honeycomb panels finished with a decorative veneer which is treated with a fire retardant. The application of fire retardant treatment (FRT) is required especially for materials with low flammability surface. However, its application can change the properties of wood. A digital image correlation method (DIC) was used to investigate the deformation of fire treat and non-fire treat surfaces. Wood sandwich panels with Bubinga Waterfall decorative veneer were used in this study. The average full field deformation of surfaces was measured after exposure at high relative humidity. The results confirmed that FRT panels have more deformation than NFRT after moisture exposure. The 2D DIC method appeared as a suitable method to analyze and identify local deformations on wood surface panels.

Keywords: Digital image correlation, DIC 2D, aircraft furniture, wood veneers, Bubinga waterfall.

Resumo

Móveis de aviões executivos são feitos com laminas decorativas tratadas com um produto ignifugo coladas num painel de nido de abelha. A aplicação de um producto ignifugo é necessário especialmente para materiais com superfície de baixa inflamabilidade. No entanto, a sua aplicação pode alterar as propriedades da madeira. O método de correlação de imagem digital (DIC) foi utilizado para analisar a deformação de paneis ignífugos e não ignífugos. Painéis de mobiliário de aviões com laminas decorativas de Bubinga Waterfall foram utilizados neste estudo. O campo de deformação da superficie du painel foi medido após alta exposição de umidade. Os resultados confirmaram que os painéis ignífugos (FRT) tiveram mais deformação que os painéis não ignífugos (NFRT). Foi constatado que o método de DIC 2D é um método adequado para analizar e identificar deformações locais em superfícies de painéis.

Palavras-chave: Correlacao de image digital, DIC 2D, mobiliario de avioes executivos, Laminas decorativas, Bubinga waterfall.

1. Introduction

Decorative veneers in the forest market are one of the most expensive products. The great importance and high value as a product is due to the degree of quality, appearance of the trees and their relative availability in the forest (CASSENS, 2002). Manufactures of decorative veneers look for trees having a interlocked grain, eccentric pith, a non-uniform color, heterogeneous growth rings given that these singularities allow to obtain patterns and figures (CASSENS, 2002; MACGREGOR, 2004). Decorative veneers, plywood, wood and wood based panels can be treated with fire retardants. Its application is required, particularly for materials with low surface flammability, because they will cause a delayed ignition, reduced heat release rate, and slow diffusion flames of fire (ASTM E108 2013). Nevertheless, fire retardant treatment (FRT) usually leads to reductions in the mechanical properties of wood (VICK E GROOT, 1990; LAUFENBERG et al., 2006), complicate the binding of phenolic adhesives for plywood (VICK E CHRISTIANSEN, 1993), vary the quality of wood surface (AYRILMIS et al., 2006; TANRITANIR E HIZIROGLU, 2006; DUNDAR et al., 2008a, 2008b), increase the hygroscopicity of wood (AYDIN et al. 2006) and vary the dimensional stability of plywood panels (CANDAL et al., 2011). In the aviation industry, decorative veneers with FRT are used to make aircraft furniture. They are glued on a honeycomb sandwich panel which has three elements: two high-density face sheets bonded to a low-density core (honeycomb). Sandwich panels with honeycomb core is commonly used in aerospace structures in various applications such as floor panels, control surfaces, external radomes, access panels, rocket purposes and as substrates for decorative veneers in aircraft furniture (AYDIN e KAYRAN, 2009). Panels are frequently made with aramid paper impregnated with a phenolic resin (KASSAPOGLAU, 2010a). These panels can resist exposure to hot and humid environments. Kuhbander et al. (1990) found in sandwich panels with a core of aramid (Nomex®) that the mass was increased by 0.5% and the compression and tension properties showed similar results after five years of exposure. This was later confirmed by Forgaty (2010). Later Charrette (2013) also obtained similar values, a mass of water absorbed below 0.7% after one week of exposure. In addition, shear resistance decreases about 20% (considered less critical) when the panels were aged at 60°C and 80% RH. As a substrate, this sandwich panels can offer very high stiffness, particularly in bending, at low weight. Its primary function is mechanical. It restricts the deformation of the surface of the veneer layer caused by a rapid response to changes in humidity due of its thinness.

Modern methods based on digital image processing are able to provide full field (localized deformations) measurements with high resolution. The digital image correlation method (DIC) is a non-contact optical method that acquires images of an object during deformation and performs image analysis to obtain quantitatively the full field in-plane displacements and strains (SUTTON et al. 2009). This technic is an excellent tool to study the behavior of materials and structural components subject to mechanical tests or environmental conditions. For this reason, researchers are interested on a strain map over an entire specimen surface (CINTRON e SAMOURA, 2008). The DIC method has several applications in wood research, such as study of mechanical properties (CHOI et al., 1991; DAVIM et al., 2007; JEONG et al., 2010; LI et al., 2013), physical properties (MURATA e MATSUDA, 2006; PENG et al., 2011; PENG et al., 2012), and drying wood performance (KANG et al., 2013). This article aims to study the effect of a fire retardant treatment on wood surface deformation of sandwich panels used in aircraft furniture by means of the digital image correlation method (2D DIC).

2. Materials and methods

Material

Wood sandwich panels of aircraft furniture

The sandwich panels are made with plywood, glued with a neoprene-based adhesive on a honeycomb panel - Nomex®. Plywood is composed by an outer decorative layer and two inner layers of poplar, *Populus sp* (Figure 1). For this study treated (FRT) and untreated (NFRT) panels with fire retardant (phosphate – based) were used. A decorative veneer of Bubinga waterfall (*Guibourtia spp*) obtained by rotary cutting was used as outer layer. This species shows patterns or figures in their surfaces which are related to the anatomical structure such as distribution and frequency of vessels, interlocked grain and knots. One sample per decorative layer with presence or absence of FRT was cut. A total of 2 samples of dimensions 100 x 100 x 150 mm were evaluated. All samples were initially placed in a conditioning chamber at a temperature of 20 °C and a relative humidity of 40% (RH) until reach the wood equilibrium moisture content CHE 8%.

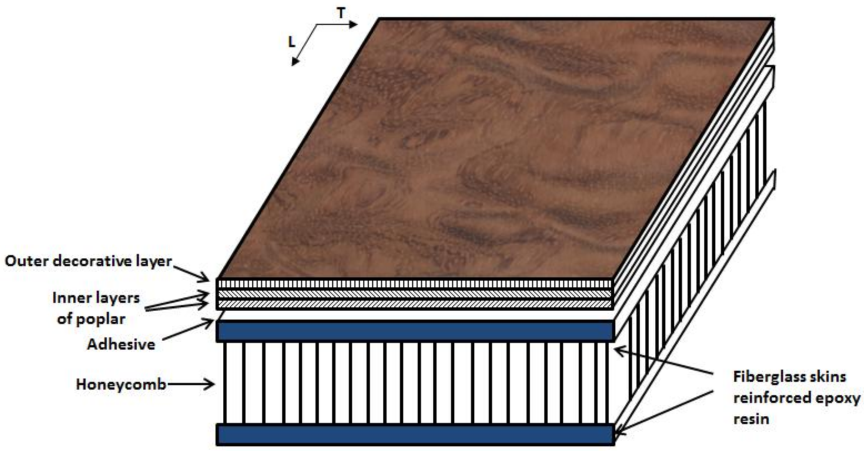

Figure 1. Wood sandwich panels used on aircraft furnitures.

Methods

Preparation of speckles on veneer surface

A white color acrylic spray paint was applied on veneer surface creating an adequate speckle pattern. The color of veneer, the random distribution, and the size of speckles (range of 10-20 pixels) formed a sharp contrast for measurement of displacement and strain using DIC 2D (CINTRON e SAOUMA, 2008; LI et al., 2013).

Digital image correlation method (DIC 2D)

The basic principle of 2D DIC is to select a subset of pixels (points P, Q) around an area of interest in the reference image. This subset is used to track its corresponding location in the deformed image (points P', Q') as illustrated in Figure 1.

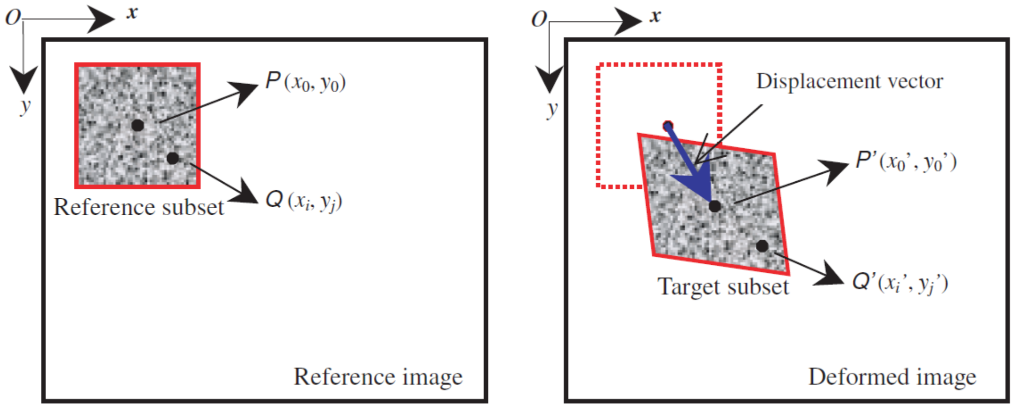

Figure 2. Schematic illustration of a reference subset before and after deformation (PAN et al., 2009)

Based on the assumption of deformation continuity of a deformed solid object, a set of neighboring points in a reference subset remains as neighboring points in the target subset. Thus, shape function or displacement mapping function can be applied

$$x'_i = x_i + u\,(x_i, y_i) \qquad (1)$$

$$y'_j = y_j + v\,(x_j, y_j) \qquad (i,j=-M{:}M) \qquad (2)$$

To evaluate the similarity degree between the reference subset and the deformed subset, a cross-correlation (CC) criterion or sum-squared difference (SSD) correlation criterion must be predefined. A normalized cross correlation function (NCC) (TONG, 2005) is often employed for optimally matching patterns and estimating deformation parameters (u, v, ε_{xx} ε_{yy}). The matching procedure is completed through searching the peak position of the distribution of correlation coefficient. Once the correlation coefficient is detected, the position of the deformed subset is determined.

$$C_{NCC} \sum_{i=-M}^{M} \sum_{j=-M}^{M} \left[\frac{f(x_i y_j)\, g(x'_i y'_j)}{\bar{f}\bar{g}} \right] \qquad (3)$$

$$\bar{f} = \sqrt{\sum_{i=-M}^{M} \sum_{j=-M}^{M} [f(x_i, y_j)]^2} \qquad (4)$$

$$\bar{g} = \sqrt{\sum_{i=-M}^{M} \sum_{j=-M}^{M} [g(x'_i, y'_j)]^2} \qquad (5)$$

Where $f(x_i,y_j)$, $g(x'_i,y'_j)$ are the intensity of corresponding pixels on the image before and after deformations, M is number of pixels within the subset in X and Y directions.

After determination of the displacement within subset u and v, the strain values can be estimating by the following equations:

$$\varepsilon_x = \frac{\delta u}{\delta x} + \frac{1}{2}\left\{ \left(\frac{\delta u}{\delta x}\right)^2 + \left(\frac{\delta v}{\delta x}\right)^2 \right\} \qquad (6)$$

$$\varepsilon_y = \frac{\delta v}{\delta y} + \frac{1}{2}\left\{\left(\frac{\delta u}{\delta x}\right)^2 + \left(\frac{\delta v}{\delta y}\right)^2\right\} \qquad (7)$$

Where ε_x ε_y are the strain in x and y directions, respectively

Experimental set-up and the procedure

After surface preparation, the sample was placed in a conditioning chamber (with a 25°C and 90% humidity relative controlled) which is connected to the DIC optical image acquisition system through a window. The moisture content (MC) of each sample was hence increased until to reach its equilibrium.

A CCD camera Jai Progressive scan model CV-M4+ CL equipped with a TV Lens 200 802 1: 1.2 / 12,5-75mm (fixed focal length of 30 mm) was used to capture images of the panels before and after the equilibrium moisture content was reached. The fixed focal lens avoids the influence of image distortion caused by a zoom lens (CINTRÓN e SAOUMA, 2008; LI et al., 2013). The working distance, the resolution and file format were 107mm, 1368x1040 pixels and 256 colors bitmap (bmp) respectively. Two light-emitting diode (LEDs) were used in parallel for lighting and keep the environment light constant throughout the measurement process (Figure 3). Prior to start the experiment, the focus has been set manually to get a clear image of the sample surface and then it sets remained in position along the test. Finally, the camera sensor must be perfectly parallel to the sample surface for avoiding distortions. Weight measurements were done with an electronic balance (accuracy 0.001g). The software used for DIC analysis was VIC 2D (developed by Correlated solutions Inc., Columbia, SC USA) who analyze displacements and strain measurements in a two-dimensional contour map.

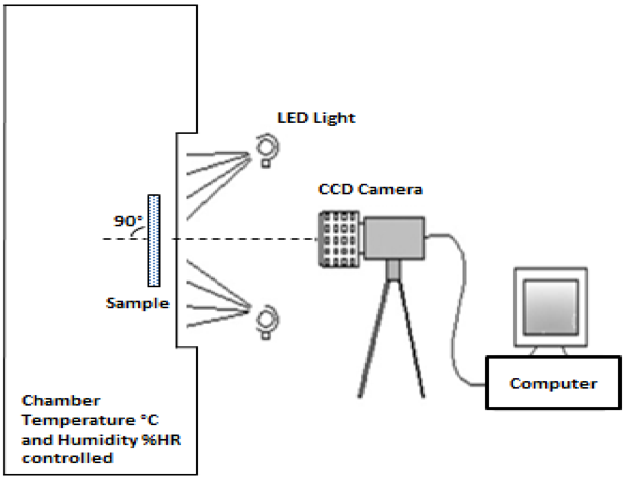

Figure 3. Experimental set up using an optical image device and environmental chamber based on Cintron e Samoura (2008) schema

Strain and displacements on wood veneer's surface

Strains in any material can be defined as the coefficient of change in length between the initial and final lengths. Therefore, strains and displacements on tangential and longitudinal directions of wood surface can be analyzed using DIC 2D technique. According to the equations 6 and 7, *x* and *y* can be considered as the tangential and longitudinal coordinates; *u* and *v* as the tangential and longitudinal displacements; and ε_{xx} ε_{yy} as the tangential and longitudinal strains, respectively. To obtain these strains, a 10 x 10mm region of interest (ROI) on wood veneer's surface was selected randomly, which covered 228 x 228 pixels. The image resolution was 0.04 mm/pixel and the subset size was 21 pixels, which is used as default in VIC 2D analysis software.

3. Results and discussion

The deformed surface of the panel after exposure to moisture is shown in figure 4. It illustrates the displacements (U, V) and strain fields (ε_{xx}, ε_{yy}) in tangential and longitudinal directions and its vectors respectively on each wood surface of the sandwich panels. As expected, wood deformation was not uniform on the surface. This local non-uniform deformation could be explained by the swelling behavior of wood veneer, orientation of wood grain and wood anatomy characteristics. Peng et al. (2011) and Peng et al. (2012) studied the deformations of radial, tangential and longitudinal surfaces in Jack pine and white spruce samples after aging using DIC. They found that the deformations vary from pith to bark and at different height in the tree in both species. These variations were explained by the influence of early and late wood in growth rings.

On other hand, the FRT and NFRT panels showed that the displacements and strains in the tangential direction are higher than in longitudinal direction (Table 1). These results are also observed according Peng et al. (2011) and Peng et al (2012) who found the same behavior in wood samples without fire retardant treatment. In addition, the FRT surface panel shows higher deformation values than those of NFRT.

The results also confirm that the presence of a fire retardant treatment on the surface of veneer increases his deformation. The hygroscopicity of the panel is also well affected by this treatment. This last result was also observed by Aydin et al. (2006).

Table 1. Values of displacement and strain on wood sandwich panel of aircraft furniture

Treatment	Moisture content (%)	Parameters	U (µm)	V (µm)	ε_{xx} (%)	ε_{yy} (%)
FRT	5.1	*Average*	47.4	29.7	0.234	0.158
		SD	5,000	4,378	0,065	0,045
		Max.	63,978	41,955	0,338	0,226
		Min.	33,771	14,367	0,000	0,000
		N°	1722	1722	1722	1722
		SE	0,120	0,106	0,001	0,001
NFRT	4.5	*Average*	20.5	17.6	0.102	0.088
		SD	5,748	5,805	0,027	0,027
		Max.	34,949	30,426	0,172	0,149
		Min.	6,563	6,079	0,038	0,034
		N°	1722	1722	1722	1722
		SE	0,139	0,140	0,0006	0,0006

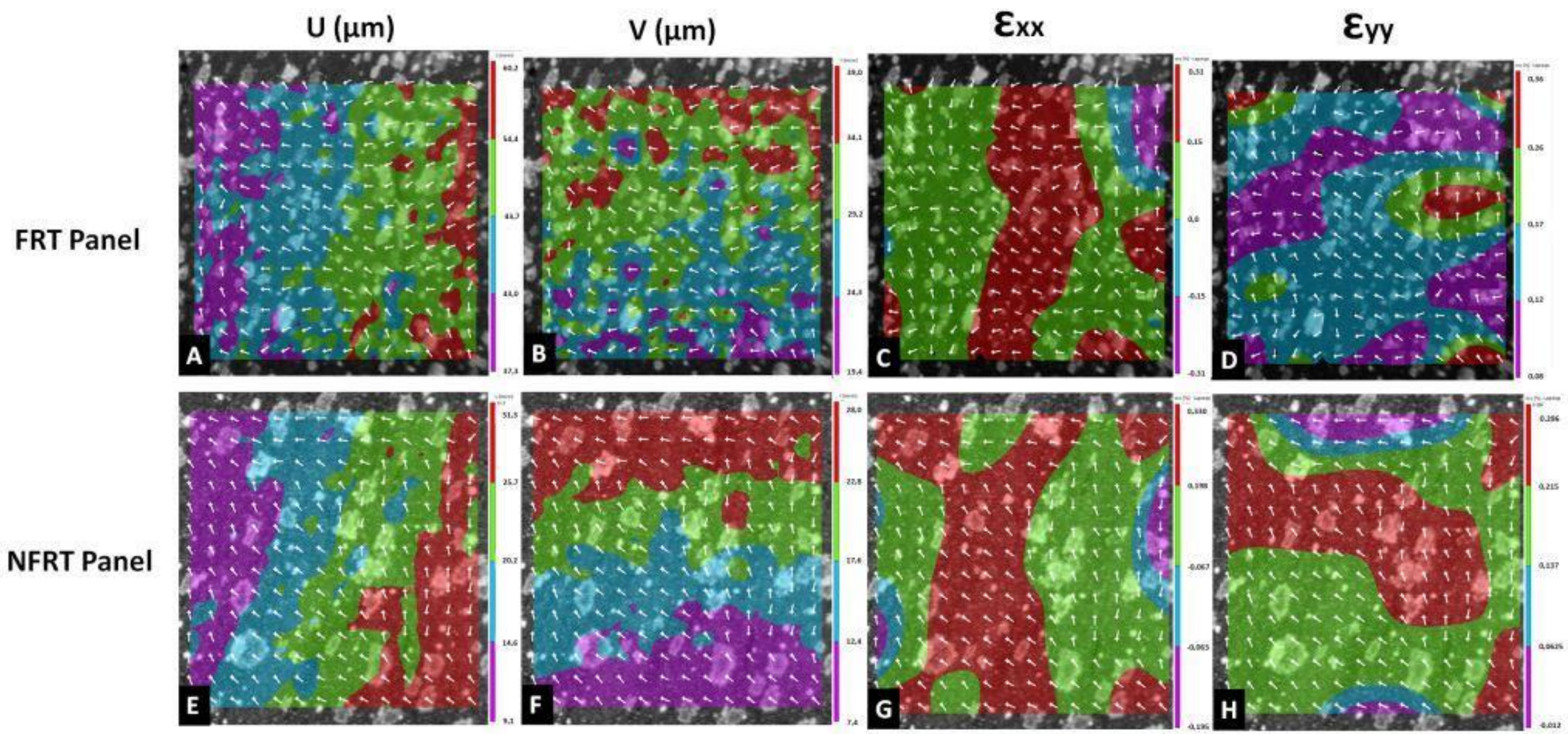

Figure 4. Displacements and deformations on Bubinga FRT and NFRT surfaces. A, E Longitudinal displacements U (μm), B, F- Tangential displacements V (μm), C, G- .Longitudinal strains ε_{xx} (%), D, H- Tangential strains ε_{yy} (%)

4. Conclusions

- The 2D DIC technique allowed to quantify and to identify zones of more or less deformation on fire retardant treated and untreated surface panels after humidification.
- The 2D DIC technique revealed that the displacement and deformations of wood surface is greater in the treated panel than in untreated panel.
- The deformations in tangential direction were higher than in the longitudinal direction of panel.
- The fire retardant treatment can increase hygroscopicity and deformations of wood sandwich panels.

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