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Photomechanical Analysis of Wooden Testing Bodies under Flexural Loadings

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Abstract**—**Application of wood in rural construction is diffused all around the world since remote times. However, its inclusion in structural design deserves strong support from broad knowledge of material properties. The pertinent literature reveals the application of optical methods in determining the complete field displacement on bodies exhibiting regular as well as irregular surfaces. The use of *moiré* techniques in experimental mechanics consists in analyzing the patterns generated on the body surface before and after deformation. The objective of this research work is to study the qualitative deformation behavior of wooden testing specimens under specific loading situations. The experiment setup follows the literature description of shadow *moiré* methods. Results indicate strong anisotropy influence of the generated displacement field. Important qualitative as well as quantitative stress and strain distribution were obtained wooden members which are applicable to rural constructions.

Keywords**—**M*oiré* methods, wooden structural material, rural constructions.

I. Introduction

WOOD versatility and availability have given strong support toward its application as structural component since many centuries [5]. In spite of that the intensification of wood as structural material deserves a complete knowledge of its mechanical properties [11].

Material mechanical behavior can be well studied by means of optical techniques [12]. These methods have been applied in static loading situations and more recently in dynamic problems, emphasizing the application of holography, speckle interferometry, classical photoeslasticity as well as *moiré* methods [9].

The *moiré* phenomenon takes place when two screens of certain mesh density are superposed and having their relative positions displaced generating optical patterns named *moiré* fringes. This relative displacement between two grids generates a third track similar to the waves, but differentiated among angles and period of the grid that generates the phenomenon. This third track is named “pattern fringes” [4].

Advantages of *moiré* techniques include the generation of a complete field displacement with low noise effects [7]. Fringes are taken as movement amplifiers showing high sensitive to relative displacements beyond low cost and reliability [4].

The application of *moiré* techniques in experimental mechanics consists in analyzing the image generated onto the object surface before and after deformation. The object grid is printed, glued or projected onto the testing object surface and deformed together with this. The optical interaction between the object grid and the reference grid will produce the fringe patterns either onto the surface before deformation as well as on the deformed one. Both groups of fringes will generate the stress distribution by means of adequate processing [8].

The pertinent literature discloses several scientific works devoted to the application of shadow *moiré* methods to determine stress distribution on bodies composed of anisotropic materials. Shadow *moiré* has obtained reliable results on the determination of isodeformation contours on bamboo specimens [1]. The highest deformation concentration on wood structure under compressive loads has been determined by use of shadow moiré [6]. Qualitative determinations of stress distribution on wooden beams under torsional loading by shadow moiré technique and compared with the theory of solid mechanics, which obtained results in close agreement [8]. Research works has also been analysed on stress distribution on cashew nuts demonstrating qualitative relation with the generated deformation [2].

Based on what it has been exposed before, the objectives of this research work can be understood as the qualitative determination of stress distribution on wooden beam under variable loading as supported by a shadow *moiré* technique.

The results of this work aim to contribute with material science and engineering for a better understanding of the wood mechanical properties to support its application as structural components.

II. Materials and Methods

The material employed in this research work belonged to the specie *Eucalyptus saligna*, which is abundant in Brazil. An EMIC DL 30000 universal testing press was employed to carry the flexural loadings on the testing bodies. The complete research work was divided into three distinct phases, as follows. (1) Destructive loading tests, (2) non destructive

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loading tests or photomechanical tests and (3) image processing. The first and the second phases were carried at the Testing Materials and Structure Laboratory at the Faculty of Agricultural Engineering in the State University of Campinas, SP, Brazil.

Destructive tests obeyed the NBR 7190/97 brazilian norms for flexural loading on wooden specimens in order to establish the loading modules applicable in the photomechanical tests [3].

Based on the preliminary destructive tests, four flexural loading increments were established to guide the photomechanical tests. These loading levels were just enough to generate sensible displacements on the *moiré* fringes. The testing press was programmed to stop as soon the selected load level was reached.

Testing bodies dimensions were reduced from those recommended by the norms in order to adequate them to the testing machine available space, in which the specimens should be positioned strictly in front of the reference grid. The dimensions reduction should keep the distance between support and height relationship as established by the norms [3]. Based on the norms NBR 7190/97, the specimens were reduced to 60 cm length, 55 cm between supports and 2,5 x 2,5 cm of cross sectional area. The norms require a length of 21 times bigger than the body width.

The photomechanical experimental setup included a SAMSUNG 6,4 MegaPixels digital camera with remote control, a 0,2 mm Ronchi grid, an Epson multimedia projector coupled to a PC to serve as white light source, as shown on Figure 01. Testing specimens were painted with opaque white color to improve contrast and positioned in front of the grid to generate the fringe patterns.

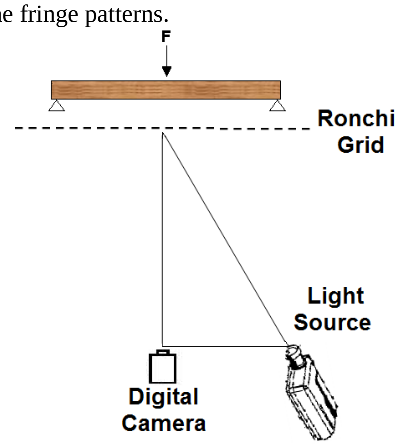


Fig. 1 Experimental setup associated to the shadow *moiré* tests

The first image generated in the experimental tests refers to the unloaded specimen meanwhile the following four images are associated to each one of the loading situations. Image processing was divided into three distinct phases, accounting with the support of ImageJ and IDRISI KILIMANJARO software to obtain the isodeformation maps.

In the first phase all the images were processed by the ImageJ software to eliminate the background, the noise effects, the light reflections, as well as to apply the filters for grid contrast [10].

In the second phase the isochromatic fringe maps were generated by means of the IDRISI KILIMANJARO software, through the whole field subtraction [2], which is based on the pixel to pixel subtraction of a image experiencing a X_i loading from another image experiencing a X_{i+1} loading of the same specimen. That method is employed to obtain the undergoing deformation on the testing specimen at two different loading levels. So, each one of the images had its corresponding pixels subtracted from the first image, i.e., the unloaded body image. Finally, a pixel intensity graduate scale associated to the testing body deformation was obtained. Image pixels were defined as image light intensity for each loading level which generates one pixel of the deformation relative value [2].

The third phase was devoted to the isochromatic lines generation from the *moiré* pattern fringes by means of the ImageJ. Pattern fringes indicate stress distribution. The stress distribution can be obtained on the top and on the bottom surfaces as well as along of a deflected beam, including the identification of the neutral line [15]. The inner state of stress can be determined through the isochromatic line analysis based on their layout and dimensions [14]. Fringes also reveals the regions exhibiting high stress concentration, since the displacement in a specific area is inversely proportional to the fringes distances, i.e., high fringes concentration indicates high stress concentration [13].

III. Results and Discussions

Table I presents the load increments applied to the testing specimens as determined through the destructive tests.

Figure 2 shows as example, one of isodeformation maps obtained from the load level Fi applied on a wooden beam and processed by the IDRISI KILIMANJARO. Figure 2 represents a full length beam loaded with 50 N carried on the specimen 1.

TABLE I
LOAD LEVELS APPLIED ON THE TESTING SPECIMENS

F_1 [N]	F_2 [N]	F_3 [N]	F_4 [N]
20	50	140	300

Fig. 2 Isodeformation map associated to the loading specimen 1 loaded with 50 N

The analysis of the color scale reveals two distinct regions showing light intensities of pixels with certain modular disequilibrium (-29 to 27). Light intensities are noted on the upper beam surface indicating the occurrence of the high compressive stress (positive pixel module) meanwhile traction stress concentration are similarly noted at the bottom beam surface (negative pixel module).

Regions presenting green color are under compressive stress influence; meanwhile red colored regions are kept under traction stress influence. This is in agreement with the pixel modules signal inversion from deformation by traction to deformation by compression.

Table II shows the pixel intensities reached by each applied load increment for each one of the three testing specimens which determines qualitatively the maximum and the minimum pixels module associated to the deformations at the beam borders.

Analyzing data of Table II it is noted that there is a disequilibrium between the pixel light intensities, indicating that anisotropical material specimens subjected to flexural loadings will experience different traction and compression loading absorption, i.e., they do not exhibit symmetric modules as the solid mechanics proposes. Isodeformation map show the negative module light intensity being always larger than the positive module indicating that wooden specimens exhibit larger deformation under traction than under compression. A possible explanation consider the wood material showing better compression load absorption which distribution on the fiber cross section along the beam is not uniform and not linear, which is different from metals and other isotropic materials.

TABLE II
PIXEL LIGHT INTENSITIES OBTAINED THROUG THE IDRISI KILIMANJARO SOFTWARE

Test	Testing Specimen 1		Testing Specimen 2		Testing Specimen 3	
	Pixel +	Pixel -	Pixel +	Pixel -	Pixel +	Pixel -
F1	6	-7	5	-5	7	-5
F2	27	-29	18	-25	17	-18
F3	59	-62	47	-65	54	-67
F4	97	-104	79	-102	79	-102

The light intensity is directly related to deformation and the average pixel intensities should be analyzed in accordance with the applied load. Figure 3 displays the graph representing the average light intensity variation as function of each applied load increment in which the curve square error falls around 3%, which is in close agreement with [1].

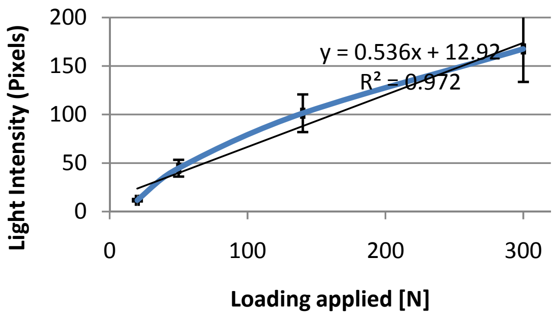
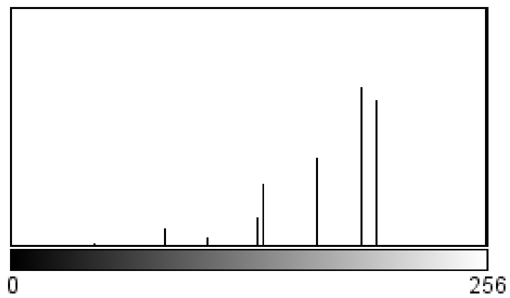


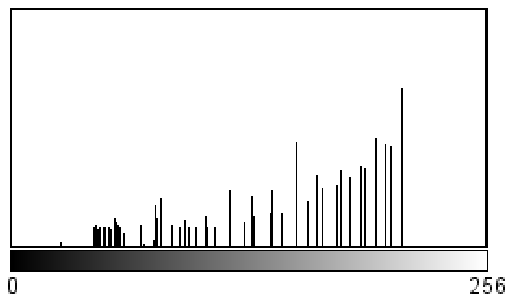
Fig. 3 Average pixel light intensity versus loading

A histogram analysis was carried to understand the dynamics of the wooden beam stress and strain behavior in a qualitative information sense by informing the pixels distribution over the body surface. The large the pixels quantity presented the more intense deformation and stress experienced by the body. Figure 4, Figure 5 and Figure 6 show the histogram for each load test carried.

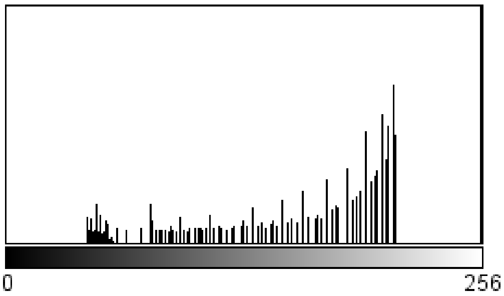
(a)



(b)



(c)



(d)

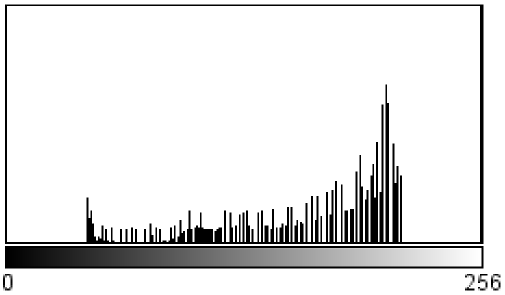
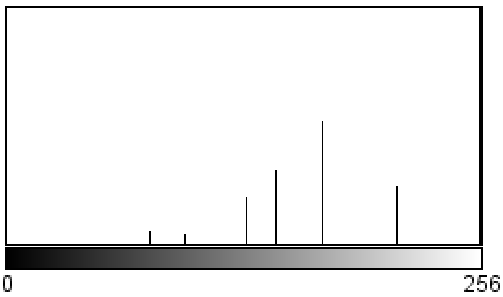
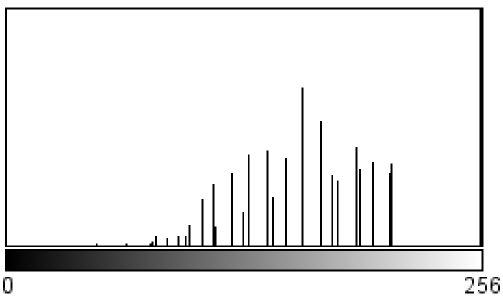


Fig. 4 Histogram for the test 01 - a) 20 N, b) 50 N, c) 140 N and d) 300N

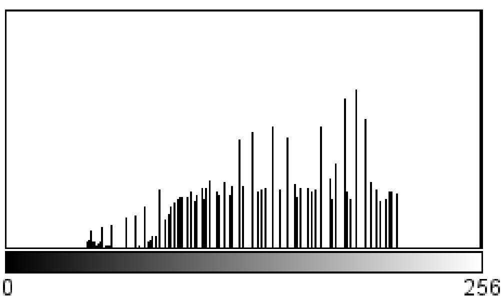
(a)



(b)



(c)



(d)

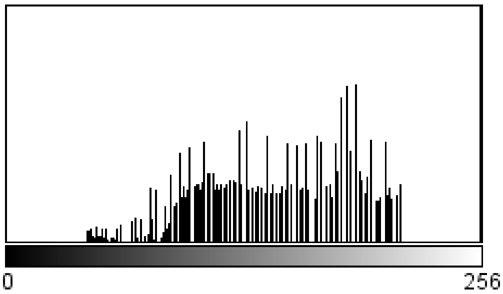
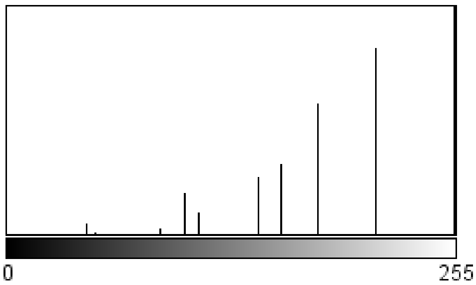
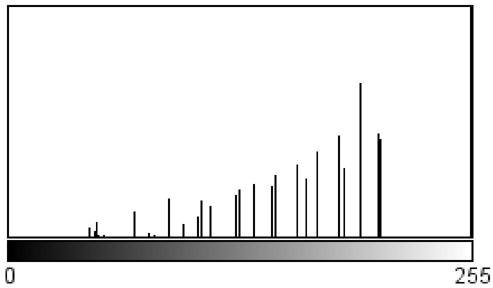


Fig. 5 Histogram for the test 02 - a) 20 N, b) 50 N, c) 140 N and d) 300N

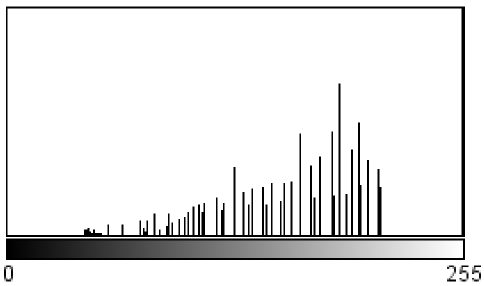
(a)



(b)



(c)



(d)

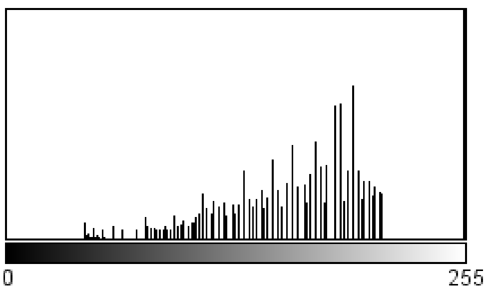


Fig. 6 Histogram for the test 03 - a) 20 N, b) 50 N, c) 140 N and d) 300N

The histograms for all the tests carried reveal that the pixels quantity increases together with the applied loads. This intensity variation can be occurred due that loading application had been increased on beam; their fibers had more deformation and, consequently induced light intensity amplification. Light intensity can be related to stress, because of deformation increasing induces an amplification its stress response, i.e., deformation induces light intensity and stress amplification. It allows to affirm a direct relationship between stress and light intensity qualitatively. Analysing stress intensity can be affirmed that projects to rural construction applying wood as structural material, loading increasing will result to increasing of fiber wood resistance. It is also noted that loading increasing promoted a better stress distribution along the specimen. It might be occurred due a better fiber accommodation, after loading applied on specimen and it allowed that deformations transferred stress concentration only on superior and inferior superficial fibers and displaced it to intermediary fibers.

Figure 7, Figure 8 and Figure 9 show the isochromatic line maps for the stress distribution analysis, in which three different colors are noted. Blue lines indicate compression stress influence, meanwhile purple color indicates traction and red color indentifies the neutral surface.

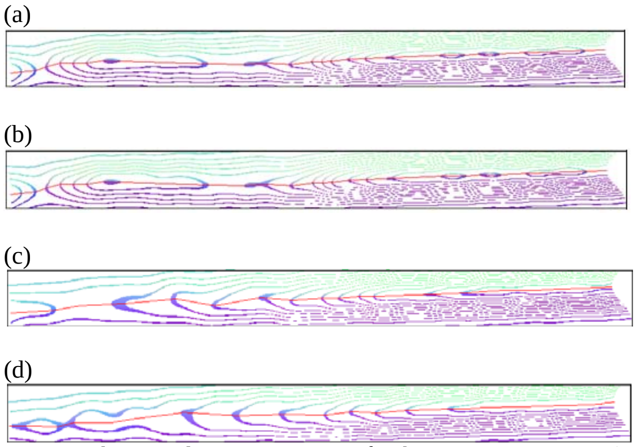


Fig. 7 Isochromatic lines representation for the testing specimen 1. a) 20 N, b) 50 N, c) 140 N and d) 300N

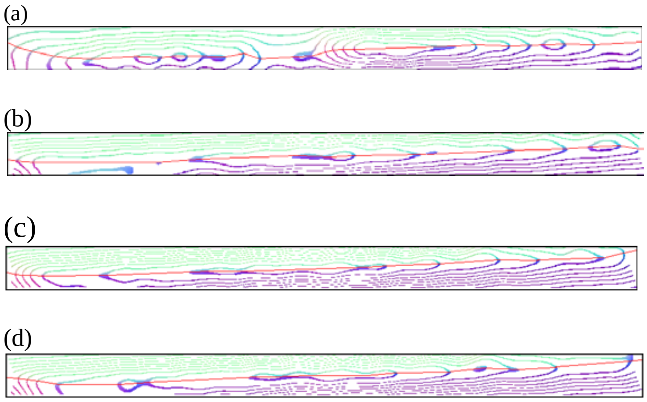


Fig. 8 Isochromatic lines representation for the testing specimen 2. a) 20 N, b) 50 N, c) 140 N and d) 300N

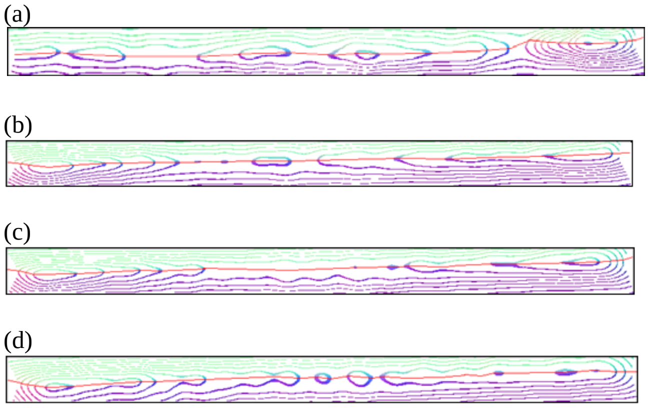


Fig. 9 Isochromatic lines representation for the testing specimen 3. a) 20 N, b) 50 N, c) 140 N and d) 300N

Isochromatic maps reveal the existence of two distinct colors separating traction and compression stress influence, separated by the neutral surface which is taken as a region of transition. The determination of the neutral surface followed the criteria described by [13]. These maps show that load increment generated stress concentration, which is indicated by the increase on the line number and concentration.

It is also noted that the neutral surface slop follows the body fibers directions, tending to increase together with the applied load, differing from the solid mechanics theory which states that neutral surface are not inclined for isotropic materials. It is possible to affirm that the neutral surface slop is influenced by the material anisotropy, which is very important for wooden structure design. It should be noted that the fibers exhibit a natural inclination with respect to the beam longitudinal axis.

IV. Conclusion

Based on what it has been exposed before the conclusions can be summarized as follows. The photomechanical tests carried on beams of *Eucalyptus saligna* allows to identify the regions under traction and compression. As the load increased, stress distribution showed to be more efficient possibly due to fiber accommodation. Wooden beam presented qualitatively, a slight influence of the compression stress which module is more intense if compared with traction modules. The neutral surface slop increases together with the applied load. This information is of major importance concerning wooden structural design associated to rural constructions. It is recommending the extension of this research topic to others wood species.

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