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Full Length Research Paper

The determination of the displacement of the wooden construction materials under load via digital image processing

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Wood is used in the building sector, in the construction of gangways and bridges, scaffolds, groundworks, building conveying systems, and in the production of the constructional components such as roofs and walls because of a diverse range of its features such as its tractablity, natural outlook, lightness and being a heat-insulator. Wooden buildings are lighter and more durable than the buildings constructed with other techniques. Earthquake security is fully ensured in the buildings constructed with the wooden framing technology. This paper aims to determine and compare the displacements of plane tree resulting from the three point bending test by using image processing based methods and comparators. It also examines the strength properties of the oven dried woods under different moisture values. An increase in the strength of the wood and a decrease in its elasticity was observed with the removal of the moisture in the wood.

Key words: Wood, displacement, digital image processing.

INTRODUCTION

Wood has been an extensively used construction material in the building sector from past to present with a diverse range of its features such as its tractablity, natural outlook, lightness and being a heat-insulator. Being a natural and organic material of construction, wood is used in the building sector, in the construction of gangways and bridges, scaffolds, groundworks, building conveying systems, and in the production of the constructional components such as roofs and walls. The loads in the building are transferred to the ground walls by forming a construction with studs and purlins. The basic principle in simple wooden frame systems is, unlike the wood masonry systems, the use of studs vertically and the use of timber beams horizontally as the components transferring the whole construction load to the ground walls. The association of the vertical and the horizontal bearings demonstrates the formation of the wooden frame system. The stone, the adobe wood, and the brick which are used as the sealant materials are the agents for the system (Uzunoğlu, 2009). This study examines the under load displacements of the woods, used as the wooden materials in the wooden constructions, in the laboratory setting. To this aim, the testing samples sized 100 × 100 × 500 mm have been prepared. These testing samples have been exposed to the triaxial test under press, and by means of the comparators the displacements of the wood samples have been observed. In addition, the photos of the samples have been taken with a 15.3 mega pixels SLR camera. The displacements have been reacquired by analyzing the taken photos by setting up algorithms on the Matlab Digital Image Processing program. The displacement results obtained from the comparators and the Image Processing algorithm have been compared.

BACKGROUND

What is digital image processing?

The Digital Image Processing is a set of techniques ensuring the alteration of the quantitative values such as brightness, definition, contrast of an image in spatial area, or the filtration of an image in the frequency area, and the formation of a new image with the alteration of its amplitude or phase values in order for the image to be better understood, interpreted, used, stored and transferred by man or computer. The image information is converted into any form wanted with the help of image processing techniques. These techniques can be examplified as image convertion, repair, conditioning, fragmentation, compression, presentation and detection (Gon-zalez and Wintz, 1987; Jahne, 1997; Ioannis, 1993). Image convertion (Ritter, and Wilson, 2001), morphological opening and closure operations (wikipedia.org, 2010), image area properties (mathworks.com, 2010) and object capture techniques (Murphy et al., 2006) are needed to determine the under load displacement amount of the wooden construction materials by means of digital image processing techniques. The coloured sample image is converted firstly to the grey level values and then to the two-level values consisted of black and white values with the help of the image convertion technique. The fixed points, which are necessary for the displacement calculation, on and out of the sample are enabled to appear clearly by using morphological operations. The central coordinate values of the fixed points appeared clearly with the object capture technique are obtained. With the calculation of the distances of the center point values along the images, the displacement values can be calculated.

The mechanical properties of various wooden construction materials

It is difficult to examine the mechanical features of wood as it is a heterogeneous and anisotropic material. All the features of its fiber direction, press, tensile strengths are higher than its horizontal strengths. The tensile strength of wood in its fiber length direction is quite big, and it is nearly two-fold of its press strength. And its rupture strength right to the fiber direction is very low. The force trying to bend the wood is in the vertical fiber direction. If the load exceeds the bending strength, the piece bends. These kinds of circumstances are encountered on the shelves carrying heavy goods, and on the sash bars of the long tables. The bending strength changes according to the morphology of the piece and the size of its section gauges. As the length and the distance of the strength points of the piece extend, it's bending strength decreases. The knots and the cracks affect the bending strength negatively (Simpson and TenWolde, 1999; Green et al., 1999). Since the wood is a material which can become swollen and contracted due to the function of its water content, its mechanical features also can change. The wood's strength right to the fiber direction against the pressure forces is low. And in the fiber direction, its strength against the shearing force is low.

Modulus of elasticity

In pines, parallel to fibre 10000 N/mm^2, right to fibre 300 N/mm^2, Oak, beech, parallel to fibre 12500 N/mm^2, right to fibre 600 N/mm^2, in plane tree, parallel to fibre 10500 N/mm^2. The density of naturally dried 10 -15% wet Oak is 800 gr/dm^3 and of pine is 550 - 600, 800 gr/dm^3. Parallel to fibre, the tensile strength of the first quality pine is 10.0 - 10.5 N/mm^2, and its compressive strength is 8.5 - 10.0, 10.0 - 10.5 N/mm^2. The specific weight of the air-dried plane is 0.63 gr/cm^3 (Simpson and TenWolde, 1999; Green et al., 1999; orman.istanbul.edu.tr, 2010; agac-turleri-ve-ozellikler.html, 2010).

METHODOLOGY

The method of the visual displacement calculation with the image processing technique

A new method based on image processing techniques has been suggested for the determination of displacement information that the breaking sample shows under the increment load in the course of time. This method is based on the follow-up of the 12 fixed points coordinated on the sample along the consecutive images. Since the point in which the sample under the increment load will break is not known, an average displacement value is obtained with the calculation of two different displacement values on the top and bottom of the sample.

The suggested visual displacement value calculation method requires 12 fixed points in total, 3 each on the top-right, top-left, bottom-right and bottom-left corners of the sample and a fixed point out of the sample; thus it fulfils the displacement calculation by determining the coordinate information of these points along the images. There are two important advantages of determining fixed points on the sample for the calculation of the displacement. The first one is the negative impact that the testing apparatus will have, as a result of a little movement, on the calculation of displacements, which is thus removed. The second is that without knowing the point the sample starts breaking, the displacement value in the middle of the sample can be obtained.

The method suggested for the displacement calculation comprises of three stages. In the first stage, the coordinates of 12 fixed points with the same colour and shape information and a fixed point out of the sample within the image are determined. In the second stage, by using the points on the top and bottom corners of the sample, two lines on the top and bottom of the sample are obtained and the vertical distance of the point out of the sample to these lines is calculated. Thus, the top and bottom displacement values are obtained in pixels. The average of these two displacement values gives the displacement information of the sample. And in the third stage, the displacement information obtained in pixels should be converted into millimeter. For this, 1 cm spaced fixed points on the sample are used, and after the equivalent of 1 cm in pixels has been obtained, the equivalent of the displacement value in millimeter is calculated.

The determination of the fixed points on and out of the sample

A three-stage method is suggested for the determination of 12 fixed points on the sample and the only fixed point out of the sample.

First step: The application of the colour filter by using the point colour

Firstly, each frame information in the coloured entry images which have the information of red, green and blue frames is normalized

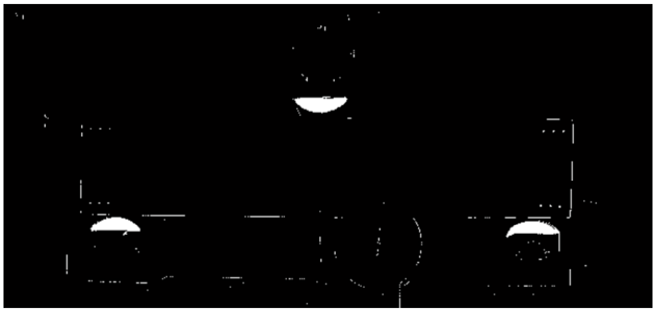
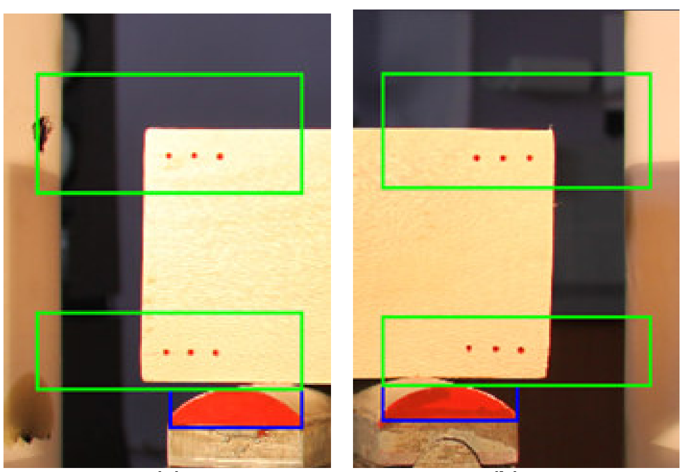


Figure 1. The colour filter result.

Figure 2. The elimination of the artificial objects and the determination of the face area objects.



(a) (b)

Figure 3. (a) Bottom-left and top-left sections (b) Bottom-right and top-right sections.

between 0 - 1. Then the filter below is applied on each frame:

$$point_{img} = (Red > 0.6) \text{ and } (Green < 0.6) \text{ and } (Blue < 0.6) \quad (1)$$

The value 0.6 on the equation above has been determined by taking the common colour value of the 12 fixed points on the sample into account. At the end of this colour filter, all the other objects, except for the ones which have the colours of the fixed points, are eliminated. After the colour filter application, the coloured entry image turns into a two-level image consisting of black and white values. The result of this stage is shown in Figure 1

Second step: The elimination of the artificial objects and the determination of the face area objects

In this step, a two-level operation is fulfilled. At the first level, the elimination of the artificial objects is ensured. And at the second level, the determination of the pier objects (face area objects) compressing the sample is done:

1. The elimination of the artificial objects:

There are many artificial objects together with the face area objects in the two-level image obtained. For the elimination of the artificial objects, two main morphological operations are fulfilled on the image: Opening (5) and Closing [6]. As the worn object pixels are cleared with the opening operation, there is a decrease in the count of pixels of the objects. Thus, the pixels around and not belonging to the object are eliminated. And in the closing operation, the object is expanded by using the determined structural element. In this way, with the association of the discrete parts of the object within a very close area, the integrity of the object is ensured (Figure 2).

2. The determination of the face area objects:

After the elimination of the artificial objects, there may still be some objects having the same colour with the face area objects on the image. For the elimination of these objects which are thought to have different geometric shapes from the face area objects, the features below about the detected objects are used (7):

Area: The total numbers of pixels in the detected foreground object
Centre: The barycenter of the detected foreground object
Solidity: The ratio of the number of pixels of the detected foreground object in the convex hull to the number of pixels on the object.
Eccentricity: The similarity value of the object configuration to the line or the circle.
By checking whether the object features obtained independently are within the limits below mentioned, all the other objects except for the target face area object are eliminated.

$$250 > Area > 150 \quad (2)$$

$$1 > Solidity > 0.5 \quad (3)$$

$$1 > Eccentricity > 0.8 \quad (4)$$

The limit values used in these equations are the features belonging to the piers (face area objects) compressing the sample. The result of this step is given in Figure 2.

Third step: The detection of the fixed points

After the determination of the face area objects, the position information was on the 12 fixed points and the detection of the only fixed point out of the sample was tried. For this, 4 sections with certain proportions are taken from the bottom-right, bottom-left, top-right and top-left areas of the sample by taking the movement information of the face area objects along the video images into account. The sections taken from the sample are shown in Figure 3. For the determination of the positions of the fixed points in these sections, the limit values below are used. The result of the determination of the positions of the fixed points on the section is shown in Figure 4. And the point out of the sample is taken as the bottom point of the top face area object.

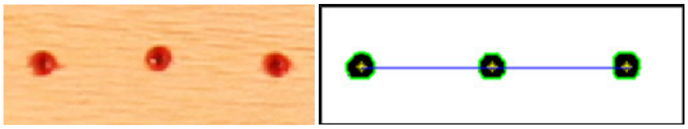


Figure 4. The determination of the fixed points on the section.

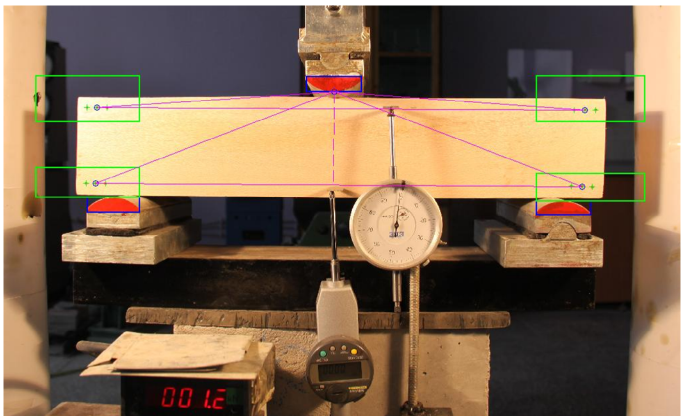


Figure 5. The calculation of the top and bottom displacement values of the sample.

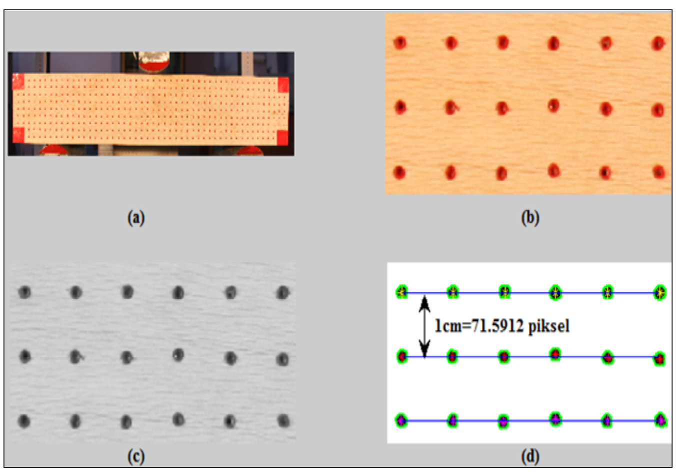


Figure 6. The conversion of 1cm into pixel value.

$$1 > \text{Solidity} > 0.8 \tag{5}$$

$$0 < \text{Eccentricity} < 0.85 \tag{6}$$

The calculation of the displacement value in the top and bottom parts of the sample

After the coordinate information of the 12 fixed points on the sample are obtained, the top and bottom displacement values in the current image are calculated as follows: The average coordinate values of each three points in the top-left, top-right, bottom-left and bottom-right corners of the sample are respectively expressed as P_1, P_2, P_3 and P_4, and the point out of the sample is expressed as P_{out}.

Accordingly, the points where the P_{out} point cuts $\overline{P_1, P_2}$ and $\overline{P_3, P_4}$ vectors vertically are respectively expressed as $P_{right,top}$ and $P_{right,bottom}$, and the coordinates of these points are calculated as follows:

$$a = \|P_2 - P_{out}\| \tag{7}$$

$$b = \|P_1 - P_{out}\| \tag{8}$$

$$c = \|P_1 - P_2\| \tag{9}$$

$$\beta = a \times Cos\left(\frac{a^2 + c^2 - b^2}{2 \times b \times c}\right) \tag{10}$$

$$d = a \times \sin(\beta) \tag{11}$$

$$z = \sqrt{a^2 - d^2} \tag{12}$$

$$P_{right,top} = P_2 - \frac{z}{c}(P_2 - P_{12}) \tag{13}$$

$P_{right,bottom}$ point is also calculated in the same way. Thus, the displacement value of the sample in its top and bottom areas can be calculated as follows:

$$Displacement_{top} \left\| P_{out} - P_{right,top} \right\| \tag{14}$$

$$Displacement_{bottom} \left\| P_{out} - P_{right,bottom} \right\| \tag{15}$$

Lastly, the displacement value of the sample in the current image is calculated as the average of the displacement values in the top and bottom areas.

$$Displacement = \left(Displacement_{top} - Displacement_{bottom}\right)/2 \tag{16}$$

The step of the calculation of the top and bottom displacement values of the sample is examplified in Figure 5.

The conversion of the displacement value in pixels into milimetre type

In this part, the conversion method used for the conversion of the displacement value in pixels into milimeter type is explained. For the conversion, the points on the sample which has been broken in the first testing apparatus are used. The conversion method shown in Figure 13 is made up of two steps. In the first step, a small section taken from the coloured sample image is first converted to the grey-level, and then to the dual level. Thus, the points positioned with 1 cm spaces on the sample are ensured to appear as the foreground object. This step is shown in Figure 6(a - d). In the second step, the points which should be horizontally abreast of each other are united on a line, and parallel lines are obtained. The average value of the distances between the lines obtained is equal to the value in pixels of 1 cm. After the application, it has been observed that 1 cm length in the image is equal to 71.5912 pixels value.

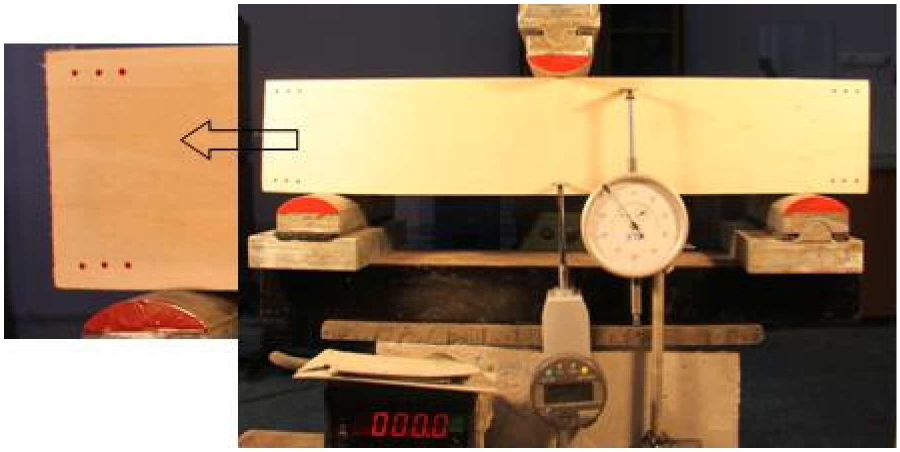


Figure 7. The testing apparatus.

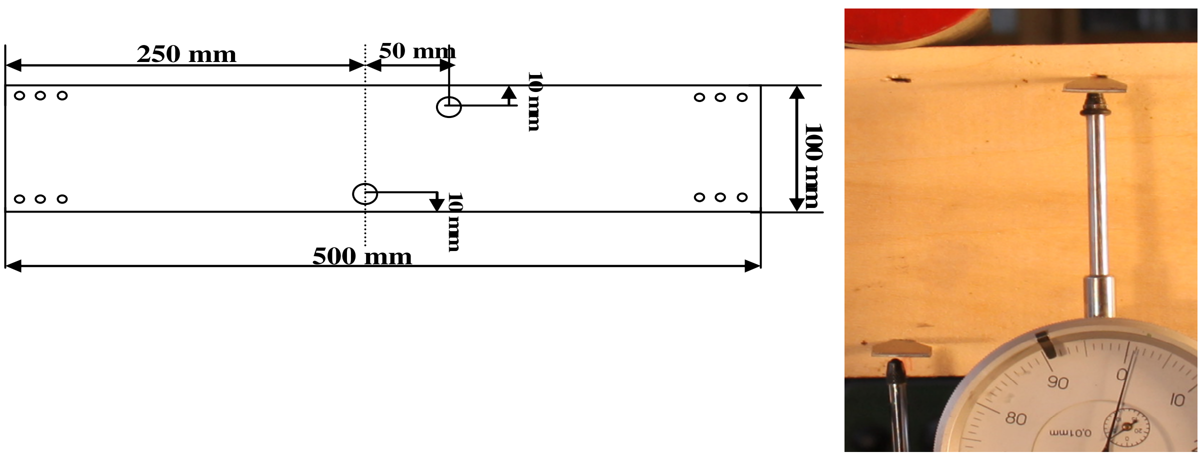


Figure 8. The placement of the comparators.

Experimental study

As the fact that effective span of the bending test apparatus is ideal for 500 mm samples has been taken into account, the testing samples have been prepared in 100 × 100 × 500 mm sizes. The testings and analyses were carried out on the last testing apparatus below which has been achieved after the trial of many different testing apparatuses. As 10 mm away from the corners of the testing sample 10 mm spaced 3 points, and in total 12 points have been established, and these points have been concretized with red colour. The point on the still pier on the top of the testing sample has been chosen as the fixed point, and the analyses were done according to this point (Figure 7).

In this testing apparatus, a digital comparator with 1% milimeter sensitivity and the manual comparator have been placed to the face area. The fact that the comparators and the load reader are in the face area and in the photo, taking direction enables the direct comparison of the displacement values obtained from the analysis of the photos taken with the values of the comparator. In addition, there turns out to be no more obligations for keeping the record of load and displacement readings. In the testing apparatus, as the lighting in the laboratory setting falls short, the lighting of the testing apparatus has been provided with 2 spotlights. The spotlights were positioned in a way that they do not cast shade on the testing sample, thus the lighting of the testing sample has been ensured. For the determination of the displacements on the samples, the comparators are placed as follows:

1. The manual comparator was placed to measure the displacements on the top of the sample. This comparator was positioned 10 mm below the top of the sample and 50 mm rightward from the center of the sample (Figures 7 and 8).
2. The digital comparator was positioned at the bottom of the sample and 10 mm above the center (Figures 7 and 8).

The application of the testings

Plane tree was used as the testing sample. Care was taken in order for the samples not to be knotty and cracked. As the prepared tree samples were obtained from wet wood and the same log, each of them was oven-dried at 50°C temperature every two days, and their moisture loss were examined and recorded in that course of time (Table 1). For the fact that the effective span of the bending test

Table 1. The oven-drying durations, moisture changes, maximum loads of plane tree samples.

Sample number	Oven- drying duration	The first weight of the sample (gr)	The last weight of the sample (gr)	Moisture loss (%)	Maximum load (kN)
1	------	3850	------	------	47.7
2	2 days	4000	3500	12.5	50.5
3	4 days	3700	3000	18.92	57.4
4	7 days	3950	3050	22.78	62.3

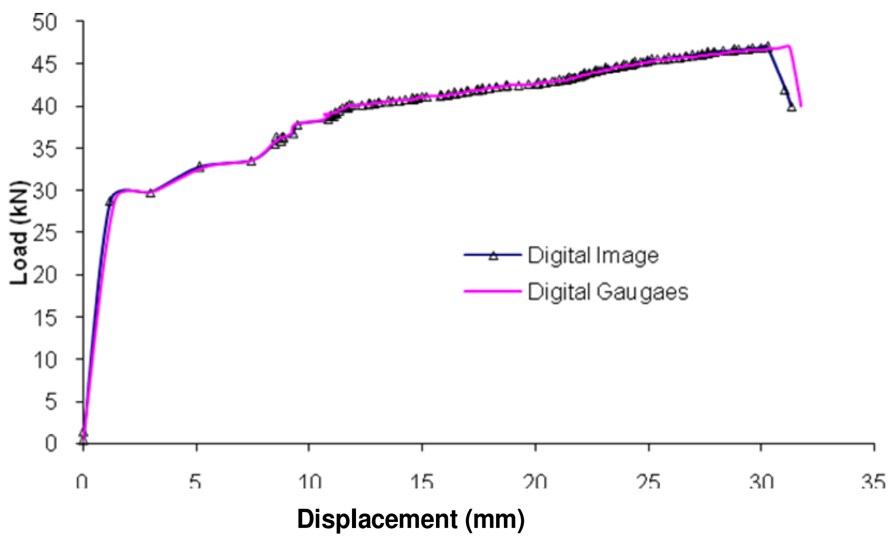


Figure 9. The load-displacement relationship of digital image and the comparator of 1st sample.

apparatus which is ideal for 500 mm samples were taken into account, the rectangular prism samples, in the three-point bending test, with maximum effective spans are placed on the hydraulic press 50 mm out and with a 400 mm interior span (Figure 7). The camera used for the determination of the attitudes of wooden samples under load has been placed, facing the axis of the sample on the platform where the machine is immobilized. Pressing the shutter of the camera manually during the testings will cause the camera to move and vibrate, and will thus cause the degradation of the pictures. Therefore, the photo shootings were done automatically with the help of a remote shutter button device placed on the camera. The photo shootings were done sporadically during the first load taking of the sample, and then they were done frequently. Thus, it has been ensured to capture the maximum moment of the sample. After the sample was broken, the photo shootings continued for a while. The continuation of the photo shootings is important in terms of making the displacement charts more accurate and interpretable. The maximum load and moisture change rates are given in Table 1.

THE VERIFICATION OF THE RESULTS OF IMAGE PROCESSING

The manual comparator placed on the top point of the support was used to test the values of the digital comparator which measures the displacement of the bottom point of the support. The displacement values in the mid-bottom and mid-top points of the support were calculated with Digital Image. The displacement values of the testing sample under load were read from the comparators, and the displacements of the mid-bottom point and the displacement relationship of the same point obtained from Image Processing are given in the Figures 9, 10, 11 and 12. And in the Figures 13, 14, 15 and 16, the pictures showing the failure of the testing samples are given.

Conclusion

In this study, more than one testing apparatuses were implemented to ensure the appropriate testing apparatus, and some analyses were carried out with the imaging technique. The problems encountered have been eradicated in the following testing apparatus and reanalyses were done. It has consequently been concluded that the testing apparatus used in the study is the most appropriate one. It was observed that the visual

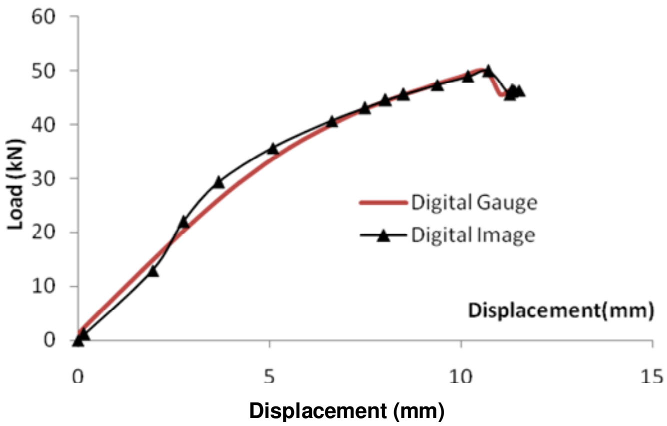


Figure 10. The load-displacement relationship of digital image and the comparator of 2nd sample.

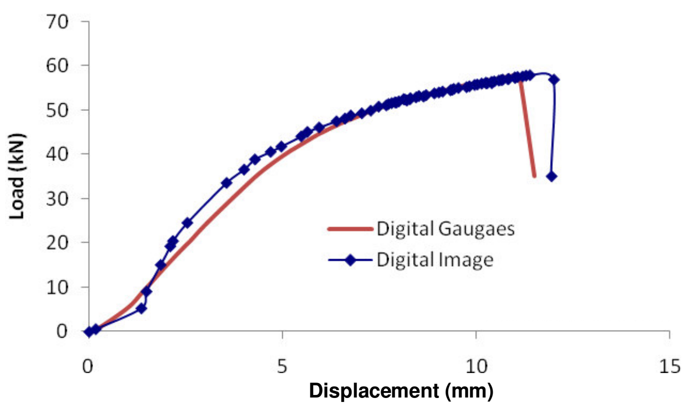


Figure 11. The load-displacement relationship of digital image and the comparator of 3rd sample

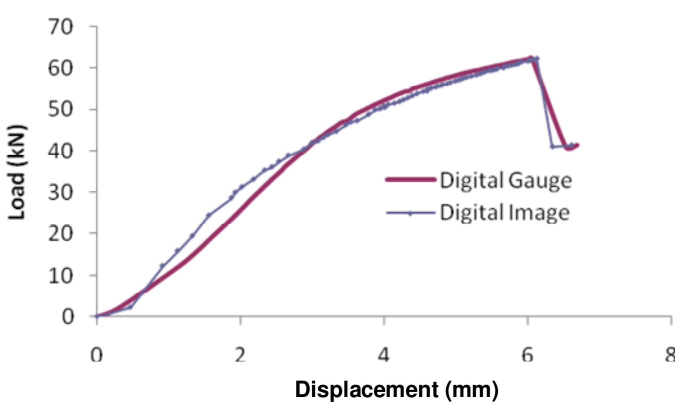


Figure 12. The load-displacement relationship of digital image and the comparator of 4th sample.

calculation of the displacements via the algorithm developed in the calculation of the visual displacements

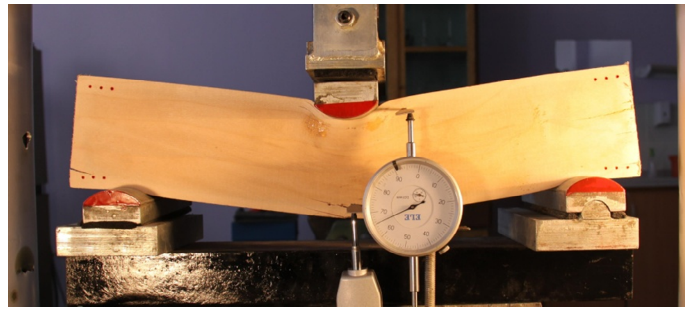


Figure 13. The failure of the 1st testing sample under load.

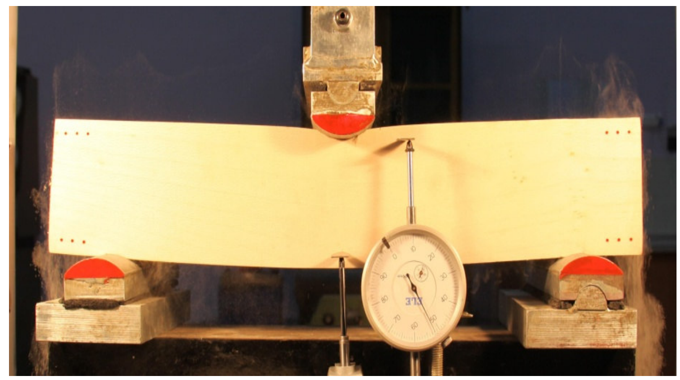


Figure 14. The failure of the 2nd testing sample under load

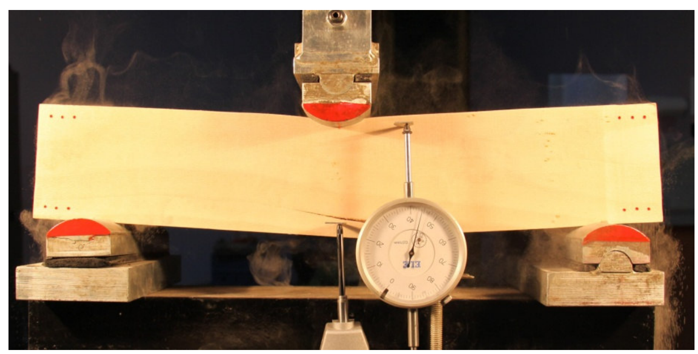


Figure 15. The failure of the 3rd testing sample under load.

by means of the image processing technique, yields better results if the proper testing apparatus is provided. It is evident that when compared, the displacement values obtained with the image processing technique are compatible with the displacement values read from the comparators. The image processing algorithm developed for this study is completely automatic, and a direct analysis is carried out on the images to be analyzed and the displacement values are obtained. The Image Processing technique is a very practical method for a detailed analysis of the displacements. The algorithms

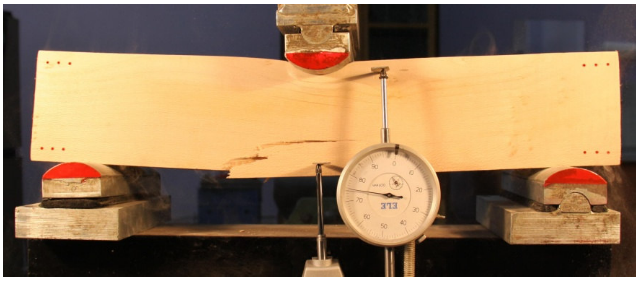


Figure 16. The failure of the 4th testing sample under load.

written in accordance with the aim of the study and the calculation of the displacements are quite simple. When the Figures are examined, it was observed that as a result of the moisture loss there is an increase in the strength of the wood, and a decrease in its deformation ability. The use of a high definition camera in the image processing technique increases the sensitivity, which generates a need for using high capacity computers to rapidly analyze the images obtained.

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