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Determination of strain distributions of solid wood and plywood in bending test by digital image correlation

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Abstract

Aim of study: In this study, it is aimed to compare displacement and strain fields of the plywood obtained from fagus coverings, oak (*Quecus robur*) and beech (*Fagus orientalis* L.) by digital image correlation method.

Material and Methods: As wood material, beech (*Fagus orientalis* L.), oak (*Quecus robur)* and plywood obtained from fagus veneers were used. Then the densities and modulus of ruptures of the test specimens were calculated. Digital Image Correlation Analysis (DIC) was developed to resolve the displacement on the surface of a specimen. Deformation of the material can be achieved by tracking the displacement of markers on the sample surface.

Main results: The results of the studies were found to be the highest static bending strenght in beech material and the lowest in plywood. The DIC technique is effective in detecting the displacement and strain, which helps to understand the bending behavior of solid wood and plywood

Research highlights: The results from this research indicate that the DIC technique is capable of measuring full-field deformations in different wood complex structures. Due to limited DIC study in the field of wood engineering, there is a need for more extensive work in the future.

Keywords: Stress distribution, Solid wood, Plywood, Image analysis.

Masif odun ve kontrplakların eğilme testinde gerinim dağılımlarının dijital görüntü korelasyonu ile belirlenmesi

Özet

Çalışmanın amacı: Bu çalışmada, kayın (*Fagus orientalis* L.), meşe (*Quecus robur*) ve kayın kaplamalardan elde edilen kontrplakların eğilme testinde yer değiştirme ve gerinim alanları dijital görüntü korelasyonu yöntemiyle karşılaştırılması amaçlanmıştır.

Materyal ve Yöntem: Ahşap malzeme olarak kayın (*Fagus orientalis* L.), meşe (*Quercus robur*) ve kayın kaplamalardan elde edilen kontrplaklar kullanılmıştır. Daha sonra, test numunelerinin yoğunlukları ve eğilme dirençleri hesaplanmıştır. Dijital görüntü korelasyon analizi, bir numunenin yüzeydeki yer değiştirmeyi çözmek için kullanıldı. Malzemenin deformasyonu numune yüzeyindeki işaretlerin yer değiştirmesini izleyerek elde edilebilir.

Sonuçlar: Yapılan çalışmalar sonucu en yüksek statik eğilme direnci kayın malzemede, en düşük ise kontrplakda bulunmuştur. Dijital görüntü korelasyon analizi masif malzeme ve kontrplak da eğilme davranışını anlamamıza yardımcı olan gerilme ve yer değiştirmenin tespitinde etkili bir tekniktir.

Araştırma vurguları: Bu araştırmanın sonuçları, Dijital görüntü korelasyonu tekniğinin farklı odun kompleks yapılarındaki tam alan deformasyonlarını ölçebildiğini göstermektedir. Ahşap mühendisliği alanında sınırlı DIC çalışması nedeniyle gelecekte daha kapsamlı çalışmalara ihtiyaç vardır.

Anahtar Kelimeler: Gerinim dağılımı, Masif odun, Kontrplak, Görüntü analizi.

Introduction

Wood is an orthotropic material; that is, it has original and independent mechanical properties in the directions of three mutually perpendicular axes: longitudinal, radial, and tangential. Elasticity implies that deformations produced by low stress are completely recoverable after loads are removed. When loaded to higher stress levels, plastic deformations or failure occur. Variability in properties can be important in both production and consumption of wood products (Glass and Zelinka, 2010).

Different methods are used in measuring and estimating the physical and mechanical properties of wood. Kelley et al., (2004) have used near infrared (NIR) spectroscopy (500 nm–2400 nm), coupled with multivariate analytic (MVA) statistical techniques to predict chemical and mechanical properties of wood. Borri et al., (2005) have studied numerical methods for reinforcement of existing wood elements under bending loads through the use of reinforced materials. Zor et al., (2016) to determine stress distribution in the bending test have used image analysis method.

DIC method has become an significant, part of the experimental world and many DIC methods have been developed (Matsumoto et al., 2013; Tasdemir, 2015). DIC method is a state of the art technique that can be used for an accurate strain measurement of material properties. It also has an benefit of full field, non-contact and considerately high accuracy deformation and strain measurements (Kwon et al., 2013; Nguyen et al., 2017).

In this paper, a 2D-DIC system using NCORR software was employed to measure the full-field strain distribution at solid wood and plywood (Blaber et al., 2015; Nguyen et al., 2017).

Material and Method

As wood material, beech (*Fagus orientalis* L.), oak (*Quecus robur)* and plywood obtained from fagus veneers were used. Beech and oak wood from Donmez Forestry Products Company in Bartin province, plywood plate from Oztürk Plywood Company in Duzce province were supplied. It has been noted in the selection of wood material is perfect, good smooth, knotless, not including reaction wood, no fungi and insect damage. Samples were cut properly TS 2470, according to TS 2474 with carefully radial, longitudinal and tangential directions. Figure 1 have showed dimension of sample and test configuration. After that all wood materials were kept for 7 days under standard air conditions (environment temperature 20 ± 2 °C, relative air humidity 65 ± 5%). The average density values of the beech, oak and plywood were 0.72 g/cm^3, 0.73 g/cm^3, and 0.70 g/cm^3, respectively.

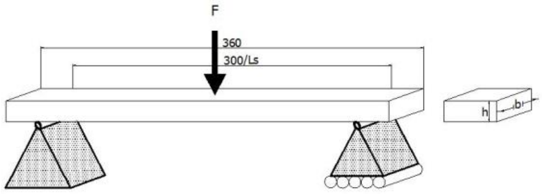

Figure 1. Dimension of sample and test configuration

Densities and modulus of ruptures of samples were calculated by equitation (1) and (2), respectively.

$$d=m/V \qquad (1)$$

where d is density of wood materials (gr cm^{-3}), m is oven dry weight of wood materials (gr) and V is volume of oven dry of wood materials (cm^3).

$$\sigma=1{,}5\cdot F\cdot Ls/b\cdot h^2 \qquad (2)$$

where σ is modulus of rupture (N mm^{-2}), F is maximum strength value (N) which have saved during bending test, Ls is span length (mm), b is width of wood materials (mm), h is height of wood materials (mm)

Preparation of Samples

Firstly, radial surface of all samples were painted by white spray paint and it was waited to dryness. Then, black paint was sprayed by brush randomly. In Figure 2, before and after painting of beech sample was given.

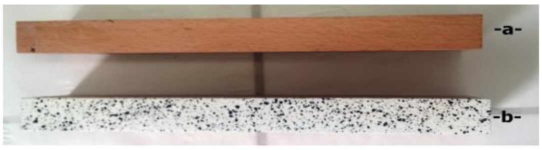

Figure 2. Overview of before (a) and after (b) painting of beech sample

Digital Image Correlation Analysis (DIC)

DIC was developed to resolve the displacement on the surface of a specimen by correlating subimages of a sequence of images, one before loading and several images during loading. Deformation of the material can be achieved by tracking the displacement of markers on the sample surface. (1)

Before the test, an image analysis set-up was made. The camera (Basler ace camera, 1624 px x 1234 px, acA1600-20gc) was connected fire wire (IEEE1394) protocol to a single desktop computer (CPU i5, 8GB RAM, 1TB Hard Disk Drive (HDD). Images were acquired and examined by means of LabVIEW Vision Builder AI for Windows. National Instruments Vision Builder for Automated Inspection is a configurable machine vision development environment (VBAI) (Nopens et al., 2008; Thalmann et al., 2003).

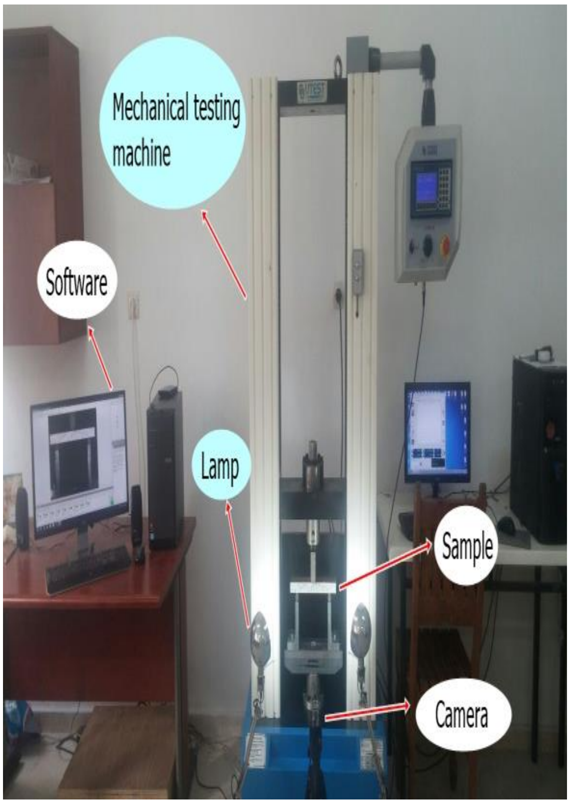

Figure 3. Photo of bending setup equipped with a DIC system.

The images collected during the experiments are then processed using Ncorr to estimate the displacement and strain fields (Pan et al., 2009; Harilal, 2014). Ncorr program, can be used in any material that could hold fine speckle pattern on its surface under study and composite material is new area under exploration with the use of Ncorr (Ghani et al., 2016; Blaber et al., 2015).

The overall flow of how the program is used for various applications is shown in Fig.4

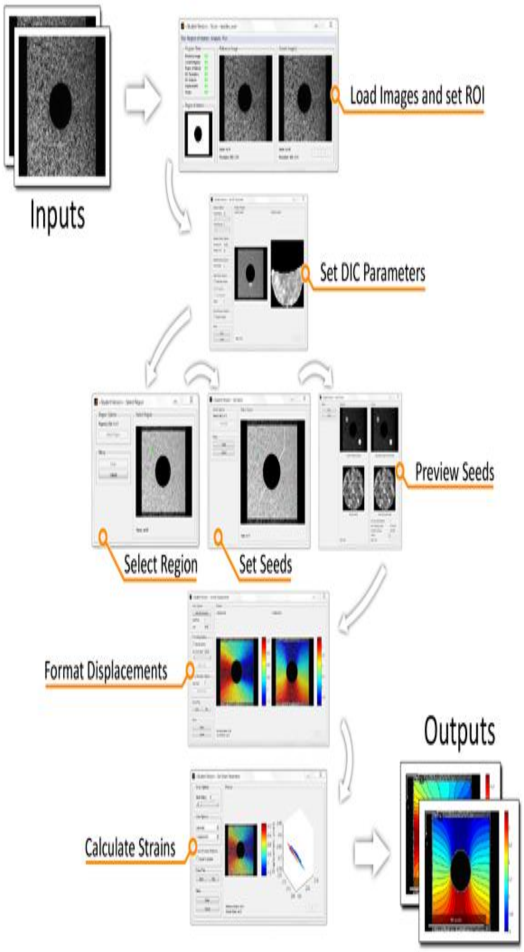

Figure 4. The overall flow of how the program is used for various applications (URL1, 2017).

Results and Discussion

Static Bending Test

Static bending tests of samples were carried out by universal test machine. To determine deformation distribution images were taken during tests continuously. Table 1 show bending strength values of the solid wood and plywood and Duncan's tests. Significant differences ($p < 0.05$) were observed in the bending strength of the samples. Significant differences were determined individually for these tests by Duncan.

Table 1. Bending strength values of the solid wood and plywood and Duncan's tests Results

Bending strength		
Beech (N/mm^2)	**Oak (N/mm^2)**	**Plywood (N/mm^2)**
97.76 (10.7) A	96.71 (8.5) A	68.14 (7.3) B

Groups with the same letters in column indicate that there was no statistical difference ($p < 0.05$) between the specimens according to Duncan's test. The values in parentheses are standard deviations.

In the Figure 5 results of static bending tests were presented.

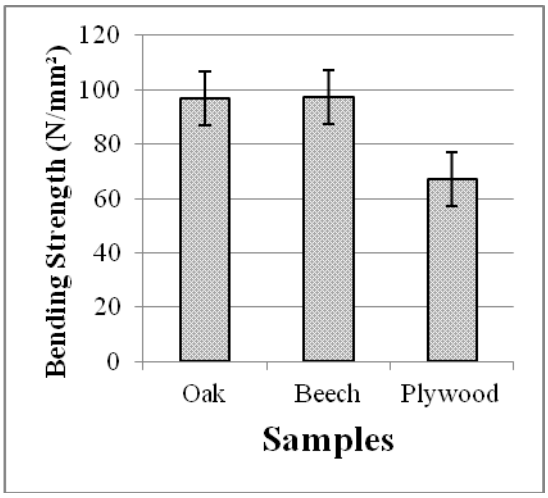

Figure 5. Results of static bending strength of samples

The highest static bending strength was obtained beech samples. This was followed, in order, by oak and plywood samples. Obtained results are similar with previous (Kasal et al., 2010).

Displacement and Strain Fields by Digital Image Correlation

The goal of the work was to compute the displacement and strain fields on solid wood and plywood using the DIC method. The displacement along x direction [mm] contours of samples under the prescribed loading obtained from Ncorr is shown in Figure 6

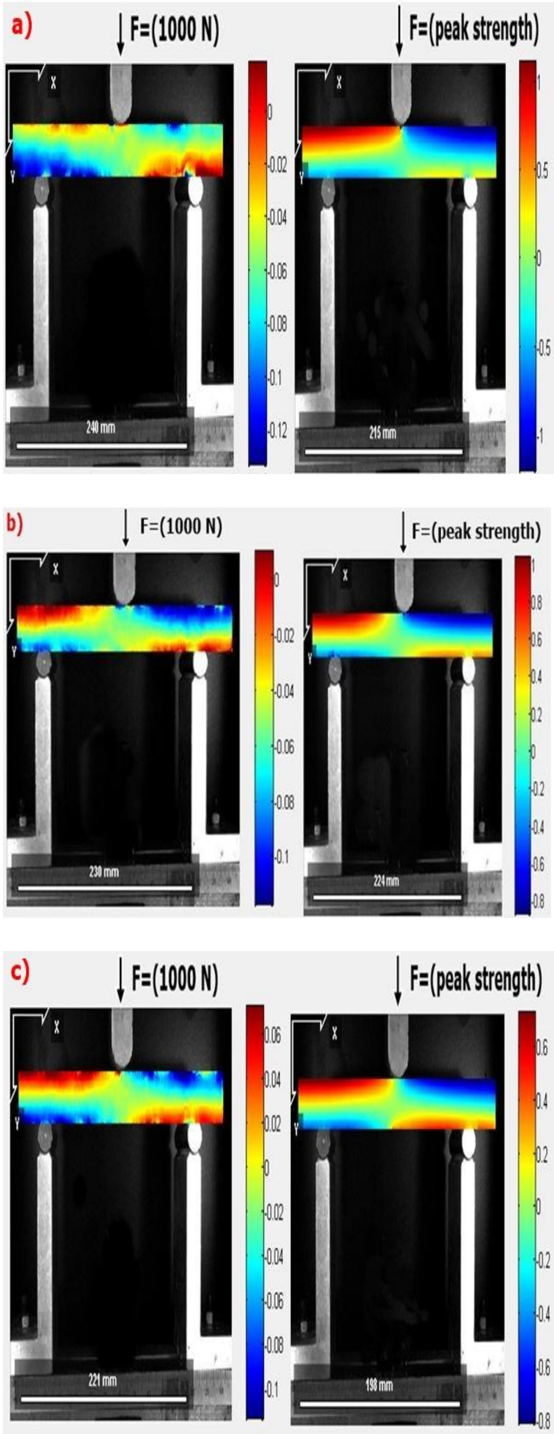

Figure 6 The displacement along x direction [mm] contour obtained for samples (a=beech, b=oak c=plywood) under bending using Ncorr

The displacement along y direction [mm] contours of samples under the prescribed loading obtained from Ncorr is shown in Figure 7.

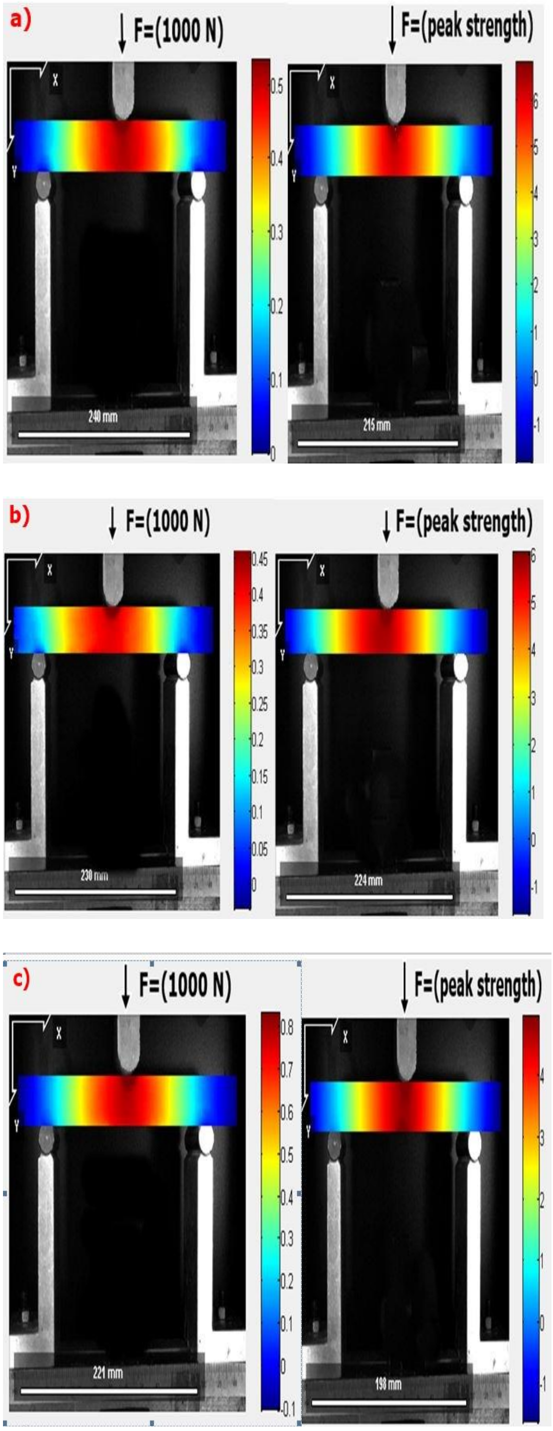

Figure 7. The displacement along y direction [mm] contour obtained for samples (a=beech, b=oak c=plywood) under bending using Ncorr

The Ɛxx (Strain along X direction) , Ɛyy (Strain along Y direction) and Ɛxy (Shear strain) contours obtained using DIC technique is shown in Figures 8, 9 and 10.

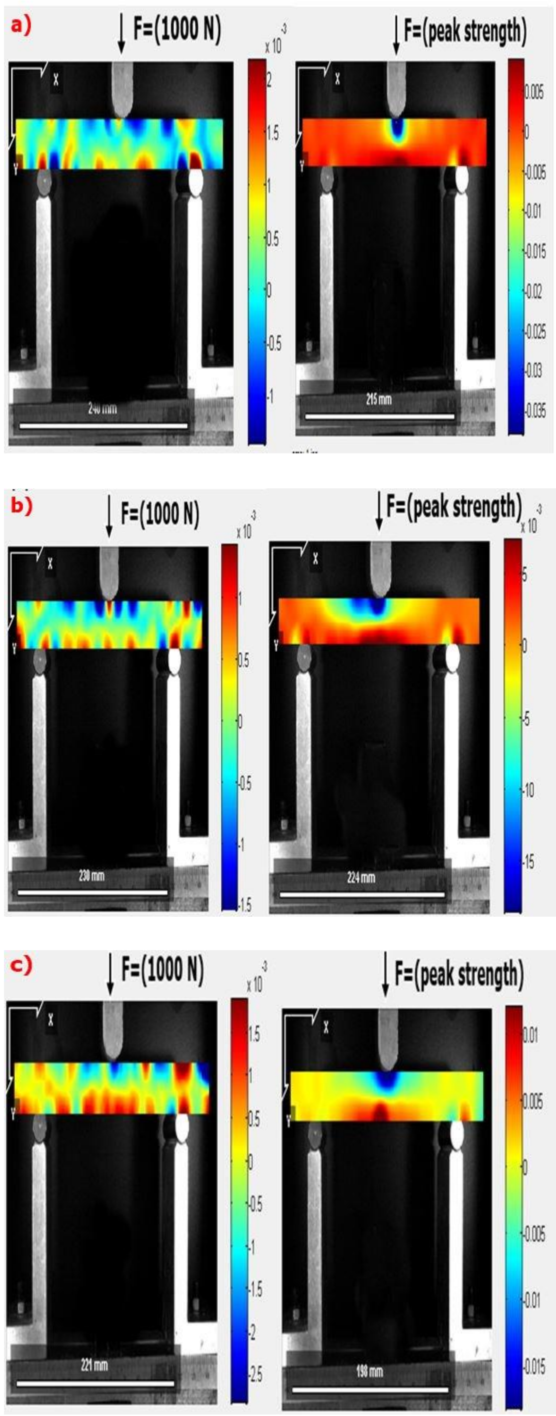

Figure 8. Ɛxx contours obtained for samples (a=beech, b=oak c=plywood)

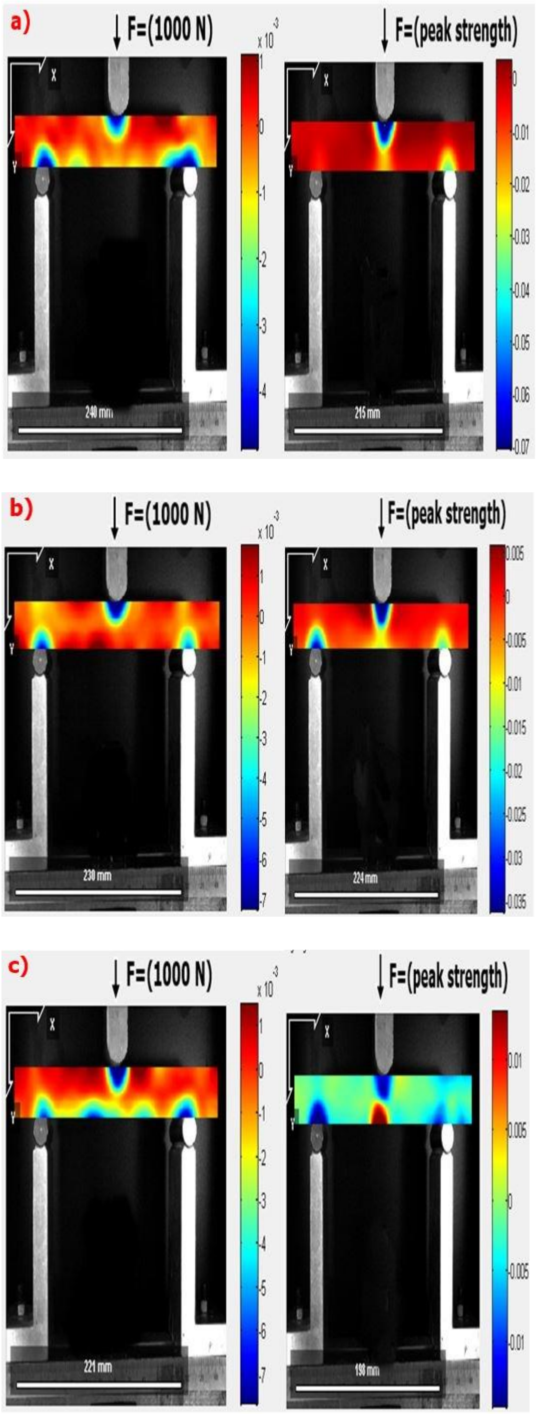

Figure 9. Ɛyy contours obtained for samples (a=beech, b=oak c=plywood)

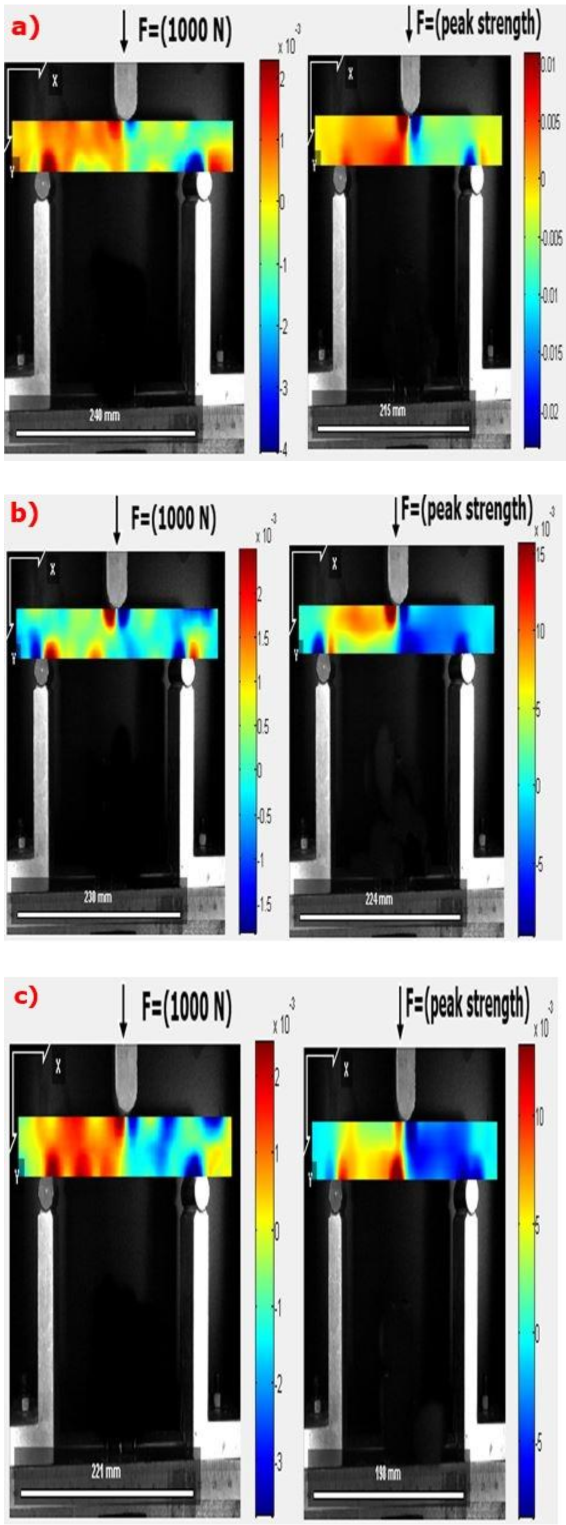

Figure 10. Ɛxy contours obtained for samples (a=beech, b=oak c=plywood)

According to the DIC results, the displacement along x and y are similar in all samples. But it is possible to observe the different behavior between solid wood (beech, oak) and plywood in the Ɛxx and Ɛyy direction. Strain fields (Ɛxx, Ɛyy) are more intense on the bottom surface of plywood. At the same time, there is no significant difference between the samples in the Ɛxy direction.

Conclusions

In this study, the strains and displacement determined from the data obtained by the DIC method. The DIC technique is effective in detecting the displacement and strain, which helps to understand the bending behavior of solid wood and plywood. The main feature of the DIC is to be able to operate in full field, thus allowing a correction in real time of the whole zone and, in special, of the measuring points (La Rosa et al., 2016).

All samples showed similar behavior in the displacement along x and y. But the plywood showed different behavior in the Ɛxx and Ɛyy direction.

The results from this research indicate that the DIC technique is capable of measuring full-field deformations in different wood complex structures. Due to limited DIC study in the field of wood engineering, there is a need for more extensive work in the future.

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