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STUDY OF MECHANICAL BEHAVIOUR OF FINGER JOINTS USING THE OPTICAL FULL - FIELD METHOD

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Abstract:
The present paper proposes a new approach to the study of the mechanical properties of finger-jointed timber (wooden elements). This type of study of mechanical behaviour of finger joints uses an optical full-field method. This method, in principle non-destructive, can be also used in conventional breaking tests. The principle of the method consists of using the Digital Image Correlation (DIC) technique in order to measure the displacement and strain fields. According to the DIC principle, the sample surface is covered by a black and white speckle pattern. The evolution of the displacement field is recorded on the specimen surface using a CCD camera and then, the displacement field can be obtained by comparing the reference image with the deformed image. The results show a global elastic non- linear behaviour of the finger-jointed sample and a brittle failure without plastic deformation.

Key words: *wood; finger joints; digital image correlation.*

INTRODUCTION

Finger joints for timber (wooden elements) have been known and used for over 80 years (Jokerst 1981). There are reliable data regarding the use of finger joints for non-structural purposes before 1930 (in automotive industry), and for structural purposes in the beginning of the 5th decade of the past century, for bridges (Egner and Jagfeld 1966).

The determination of their mechanical properties is realised according to certain existing standards (ASTM 2001a, ASTM 2001b, NLGA 2002a, DIN 1978, JIS 1970 etc.). The aim is to determine the Ultimate Tensile Strength (UTS), the Modulus of Rupture (MOR) and the Modulus of Elasticity (MOE).

By using these methods of testing, the influences of several factors on the finger joints' performances have been studied. Therefore, we can mention: the geometry of fingers (Aicher and Radovic 1999, Ayarkwa *et al.* 2000b, Bustos *et al.* 2003a, Barboutis 2007, Ayhan and Fatih 2008, Yeh and Lin 2012), the orientation of the fingers related to the direction of the load (Janowiak *et al.* 1993, Barbuotis 2007, Yeh and Lin 2012), the cutting parameters when processing fingers (Bustos *et al.* 2004, Hernandez *et al.* 2011), the wood density and the width of annual rings (Knowles *et al.* 2006), the wood moisture content and temperature (St-Pierre *et al.* 2005), the joining pressure and the gluing time (Ayarkwa *et al.* 2000b, Bustos *et al.* 2003b), the glue type (Janowiak *et al.* 1993, Ayarkwa *et al.* 2000a, Barboutis 2007, Ayhan and Fatih 2008).

The wooden species studied were (the list is not exhaustive): moso bamboo (*Phyllostachys pubescens*), ma bamboo (*Dendrocalamus latiflorus*) (Yeh and Lin 2012), black spruce (*Picea mariana* Mill.) (Bustos *et al.* 2003a, Bustos *et al.* 2003b, St-Pierre *et al.* 2005, Hernandez *et al.* 2011), Southern pine (Knowles *et al.* 2006), Obeche (*Triplochiton scleroxylon*), Makore (*Tieghemella heckelii*), Moabi (*Baillonella toxisperma*) (Ayarkwa *et al.* 2000a, Ayarkwa *et al.* 2000b), red oak (*Quercus rubra*), red maple (*Acer rubrum*), yellow-poplar (*Liriodendron tulipifera*) (Janowiak *et al.* 1993), spruce (*Picea abies*) (Aicher and Radovic 1999), oriental beech (*Fagus orientalis* lipsky.), European oak (*Quercus robur*), Scots pine (*Pinus sylvestris* lipsky.), poplar (*Populus tremula* lipsky.), Uludağ fir (*Abies bormülleriana* Matff.) (Ayhan and Fatih 2008), Sweet chesnut (*Castanea sativa* Mill.) (Barboutis 2007).

For the testing/evaluation of the wooden finger joints non-destructive methods have also been developed and used. For example, by the longitudinal-vibrations technique (Ross and Pellerin 1994) the fundamental/resonance frequency of the specimen is determined, and based on this, the Dynamic MOE is calculated. A good correlation has been detected between the Dynamic MOE and the Static MOE, as well as between the two and MOR (Bender *et al.* 1990, Ayarkwa *et al.* 2001a). The acoustic emissions technique (Sato *et al.* 1983, Sato *et al.* 1984a, Sato *et al.* 1984b, Nakao *et al.* 1986, Nakao 1990, Beall 1987, Beall 1990, Biernacki and Beall 1993, Bucur 1995, Drouillard and Beall 1990, Hwang *et al.* 1991, Fujii 1997, Noguchi 1985, Noguchi 1991, Kawamoto and Williams 2002) is based on the determination of the acoustic emissions generated by the sudden release? of energy due to the (micro)fractures? in the material under stress. It is also used for the study of finger joints, to predict their mechanical properties (UTS, MOR etc.) (Porter *et al.* 1972, Ayarkwa *et al.* 2001b, Ayarkwa *et al.* 2001c, Ayarkwa 2010).

The "acousto-ultrasonic" technique (Beall 1987, Sandoz 1992, Biernacki and Beall 1993, Sandoz 1996, Kawamoto and Williams 2002) is mainly used for the characterisation of glued joints (Reiss *et al.* 1986, Beall 1990, Biernacki and Beall 1996, Reis *et al.* 1990a, Reis *et al.* 1990b). This method combines elements of the acoustic emissions technique (signal processing) with the methods of ultrasonic characterisation (ASTM E1495). The acoustic emissions of the wood under deformations are replaced by ultrasonic emissions generated by piezoelectric devices. The signal is captured by a transducer and then later processed in the same way as in the case of the acoustic emissions technique. This method is used to study the finger joints in order to evaluate/test them (Reiss 1990, Reis *et al.* 1990b, Anthony and Phillips 1991, Anthony and Phillips 1993).

In the present study, we propose a mechanical behaviour characterisation of the finger joint using the DIC technique from the 4-point bending test. DIC is based on the analysis of successive digital images of the same sample during a mechanical test. The displacement fields are obtained by measuring the degree of similarity of a series of subsets between the image corresponding to an unloaded state and the deformed image recorded during the test. Each pixel of these images stores a grey level value due to a pattern at the surface. To avoid ambiguities in the similarity process a random distribution of grey levels can be used called speckle pattern. This pattern can be the natural texture of the specimen surface or artificially made by spraying black and/or white paints. We assume that grey level distribution follows strain of material, and that there is a conservation of the optical flow (Sutton *et al.* 1983, 1986, 1991).

MATERIALS AND METHODS

The mechanical behaviour of the finger joint sample is evaluated from the 4-point bending test. The experimental test is realised using an electromechanical press Zwick Roell Z300. The overview of experimental setup is illustrated in Fig. 1. The test is performed under displacement control and the speed of the crosshead is fixed at 1mm/min. The sample deflection during the test is measured by an LVDT transducer, and then the applied force is measured by a load cell.

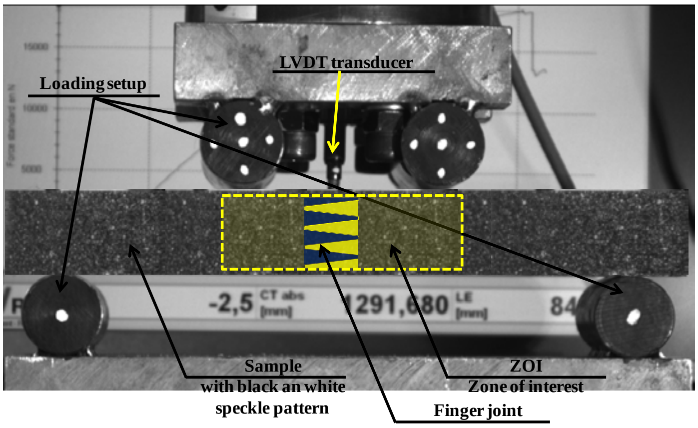

Fig. 1
Experimental 4-point bending test setup.

In parallel with the classical measurement devices (LVDT and load cell) an optical system (Fig. 2) is added in order to evaluate the sample mechanical behaviour. In this case the Digital Image Correlation (DIC) technique is employed to measure the displacement and strain fields. In accordance with the DIC principle, the sample surface is covered by a black and white speckle pattern as is shown in Fig. 1. The principle of this full-field method is based on a comparison between two images acquired during the test, one before deformation and the other after. The displacement field can then be obtained by comparing the reference image with the deformed image. As regards measurement devices, the displacement field evolution is recorded on the specimen surface using an 8-bit CCD camera. The image capture is performed at a rate of 1 frame per second and the camera is synchronized with the electromechanical press data (force and displacement).

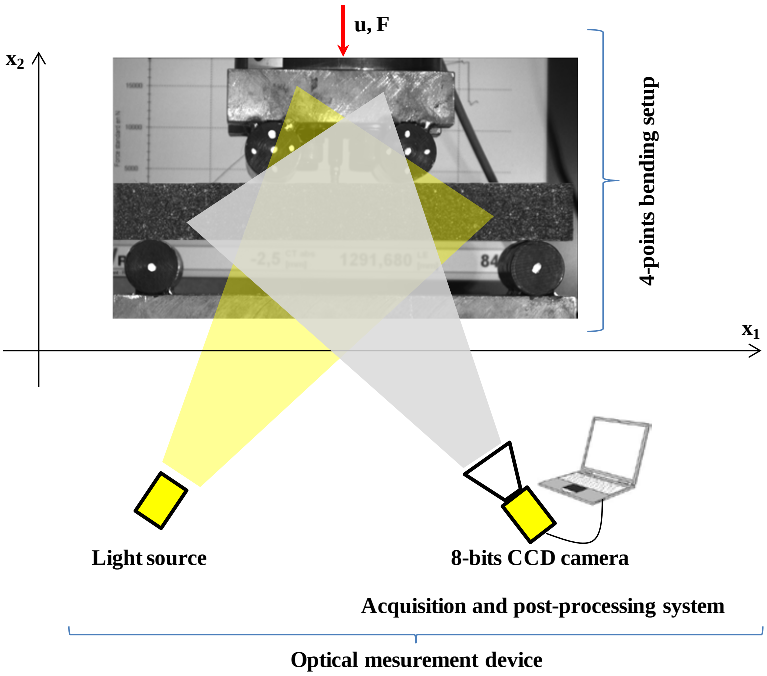

Fig. 2
Optical system.

The sample geometry and dimensions are illustrated in Fig. 3. As is shown in Fig. 3, the sample is composed of two finger jointed pieces of beech (*Fagus sylvatica L.*) timber. The geometry of the finger joint is also illustrated in Fig. 3.

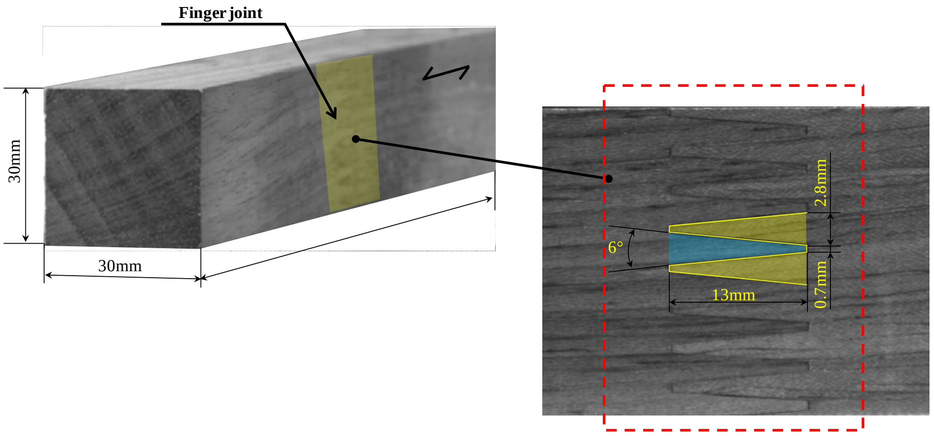

Fig. 3
Sample geometry and dimensions.

Note also that before test, the sample is conditioned in the laboratory and the moisture content of the sample, measured after the bending test, is 8%.

RESULTS

The load-displacement characteristic curve recorded during the test is illustrated in Fig. 4. The analysis of the characteristic curve reveals several aspects related to mechanical behavior of the timber finger joints during the bending test. The results show a global elastic non-linear behavior of the sample and a brittle failure without the plastic deformation. The linear elastic part observed at the beginning of the test is very small. These observations are correlated with the full-fields measurement by DIC method.

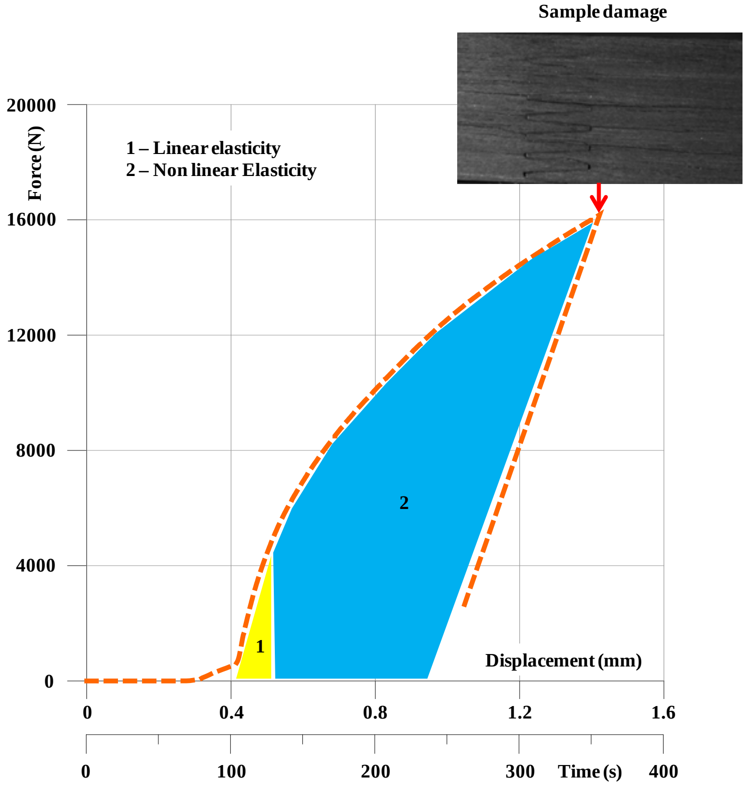

Fig. 4
Load-displacement characteristic curve.

The results obtained from the DIC measurements are plotted in Fig. 5. These results have been obtained using a zone of interest (ZOI, Fig. 2) located on surface sample between the inner bearings. According to DIC principle, this area is subdivided using subsets of 32x32 pixels². The size of the zone of interest is 83.5 by 29mm with a factor scale equal to 0.25mm/pixel. The software of correlation used here is named Correla which was developed by Pprime institute.

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As shown in Fig. 5, the neutral axis located around the middle for both samples at the beginning of the test for elastic behaviour. Beyond this limit, the neutral fibre position has a tendency to move up due to the presence of compression-tension asymmetry.

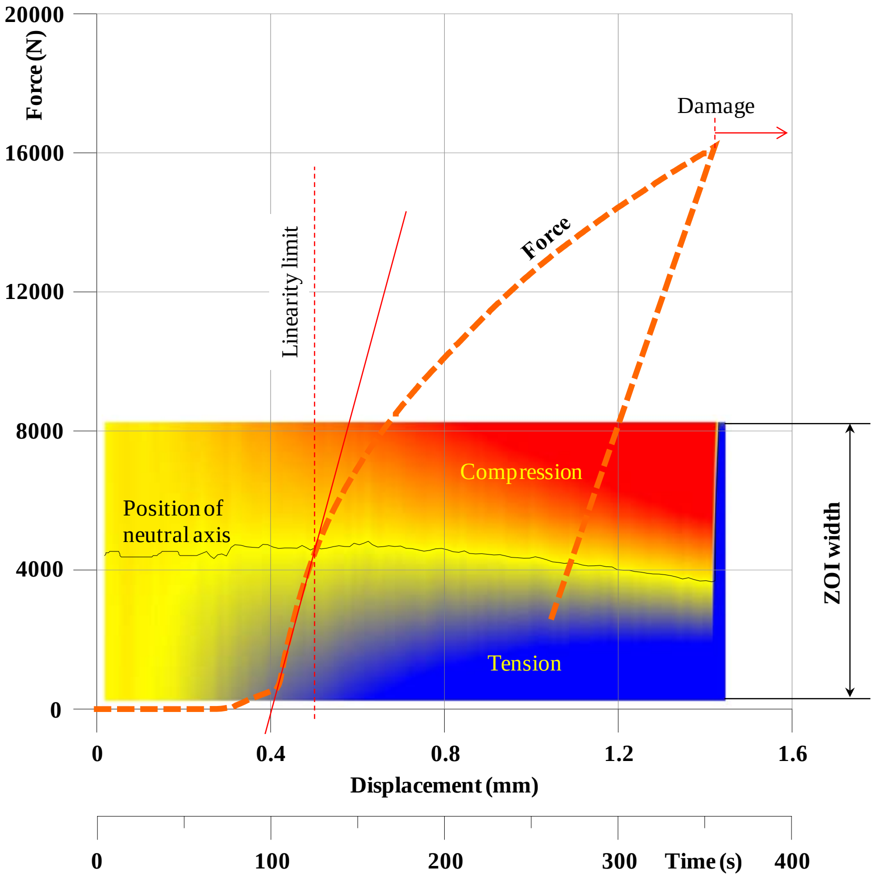

Fig. 5
Experimental longitudinal strain fields evolution vs. test time.

CONCLUSIONS

In the present study the mechanical behaviour of finger joint is analysed from the displacement and strain fields measured by DIC technique. The mechanical behaviour of the finger jointed sample is evaluated from the 4-points bending test. This methodology can be considered as a new characterisation method for wood connections instead of using conventional linear formulae based on assumptions that are not always valid.

The results obtained from the optical full field technique, show a global elastic non-linear behavior of the sample and a brittle failure without the plastic deformation. Moreover the evolution of longitudinal strains shows the presence of compression-tension asymmetry.

In conclusion, this study highlights the asymmetric and nonlinear ductile behaviors of this material during four-point bending test at room temperature thanks to digital image correlation; this mechanical behavior is characterized by the shift of the neutral fiber due to the different mechanical behaviors under tensile and compressive loadings.

In future studies, a coupling between experimental results derived from DIC with numerical simulations by finite elements analysis will be carried out. This could allow the identification of mechanical behavior of finger joint and damage level, in order to monitor the finger-jointed timber in service. As the surface of some industrial products is not usually planar, the three-dimensional DIC or digital volume correlation can be more effective.

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