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Moisture Induced Deformations in Glulam Members – Experiments and 3D Finite Element Model

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INTRODUCTION

Glued-laminated timber (glulam) is an engineered wood product (EWP) manufactured by gluing together timber laminates to create large components for structural applications. Like any other structural parts, glulam elements are commonly exposed to wetting by air humidity and drying by surrounding air. Usually in building applications direct exposure to liquid water is the result of preventable causes like faulty design, construction errors, lack of maintenance and spills. Therefore, focus here is what happens in well designed and constructed buildings within which glulam components are wetted or dried according to temporally varying moisture fluxes at surfaces of components that are exposed to air during and after construction.

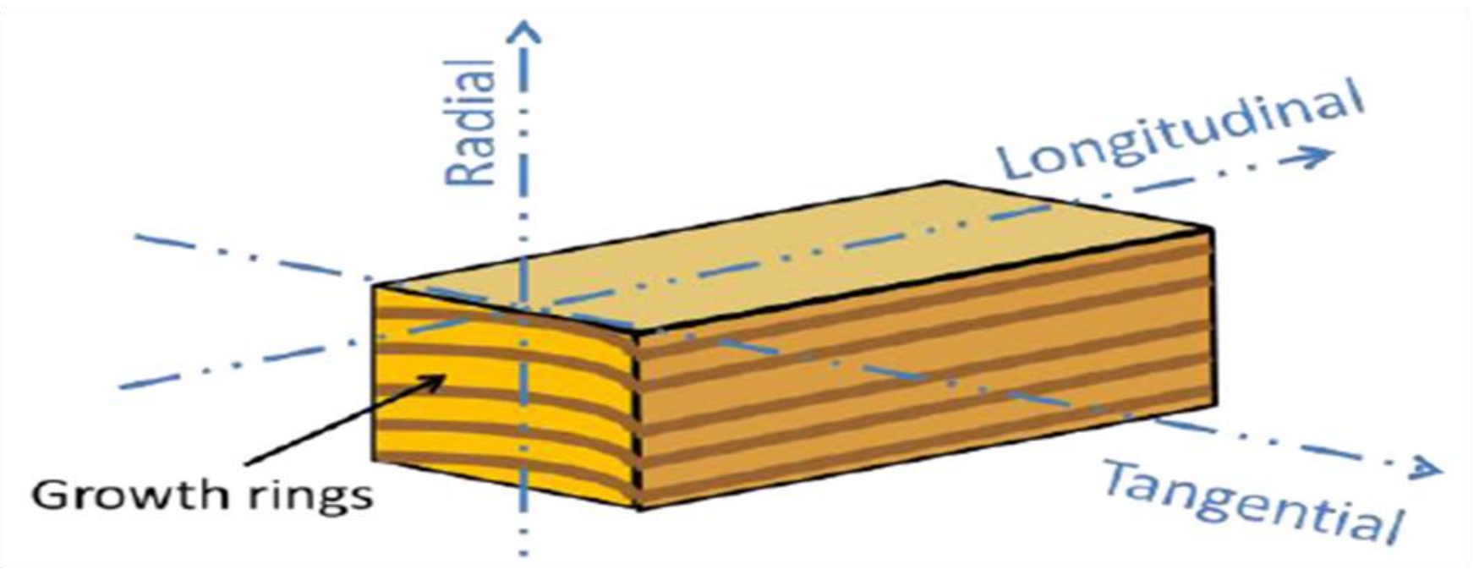


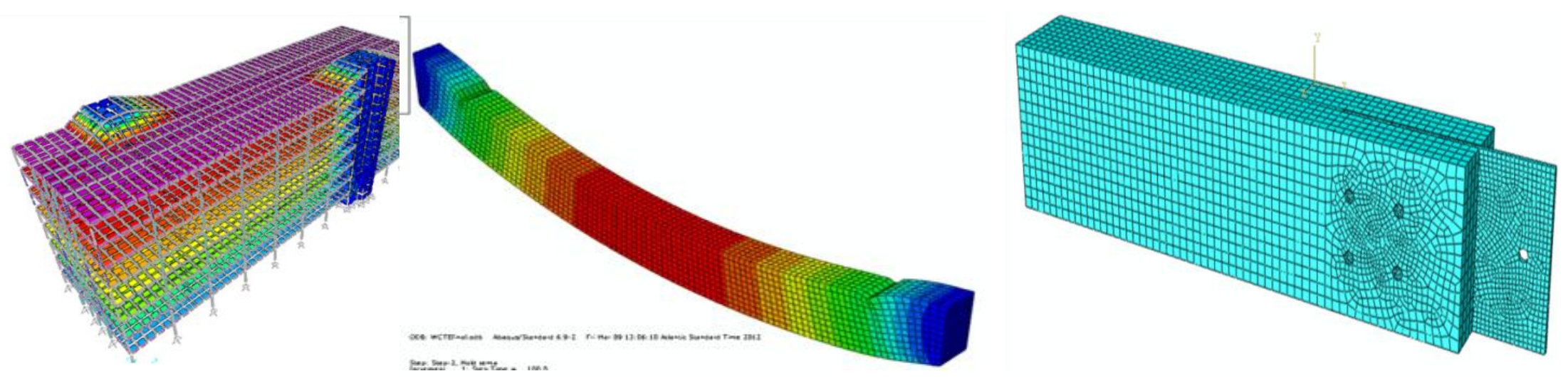
Figure 1: Principal axes of wood with respect to tree stem structure

OBJECTIVES

The eventual goal for this project is to create the capability to predict, and therefore be able to counteract, adverse deformations and material incompatibilities that can exist within hybrid buildings. Complementary investigations are underway to address other aspects of the hydrothermal behaviour of structural components of glulam and other materials (e.g. reinforced concrete) embedded within multi-storey hybrid building superstructures and glulam elements and connections.

METHODOLOGY

The modelling approach is general but illustrative through experiments that were designed to support the development of a three-dimensional finite element model capable of predicting temporally varying internal strains and external deformations of drying or wetted glulam structural elements with or without external applied forces. Those experiments were relatively simple and small scale, and are a precursor to complex experiments necessary to rigorously establish how glulam components interact with components of other materials commonly found in large hybrid building superstructures.



(a) System level study (b) Glulam element (c)Connection modelling

Figure 2: Different modelling levels

EXPERIMENTAL SET-UP

Eight scaled straight glulam members of 60 mm depth by 40 mm width by about 2.2 m long were made from 10 mm thick spruce laminates glued together with Phenol Resorcinol Formaldehyde (PRF) adhesive. The laminations were cut from commercially produced lumber that was nominally air dry (moisture content around 15 %). After fabrication specimens were stored in a conditioning chamber for four weeks at 20ºC and 65% relative humidity (RH) until they attained an equilibrium moisture content (EMC) of about 12% prior to testing The experiment arrangement is as shown in figure 3.below.

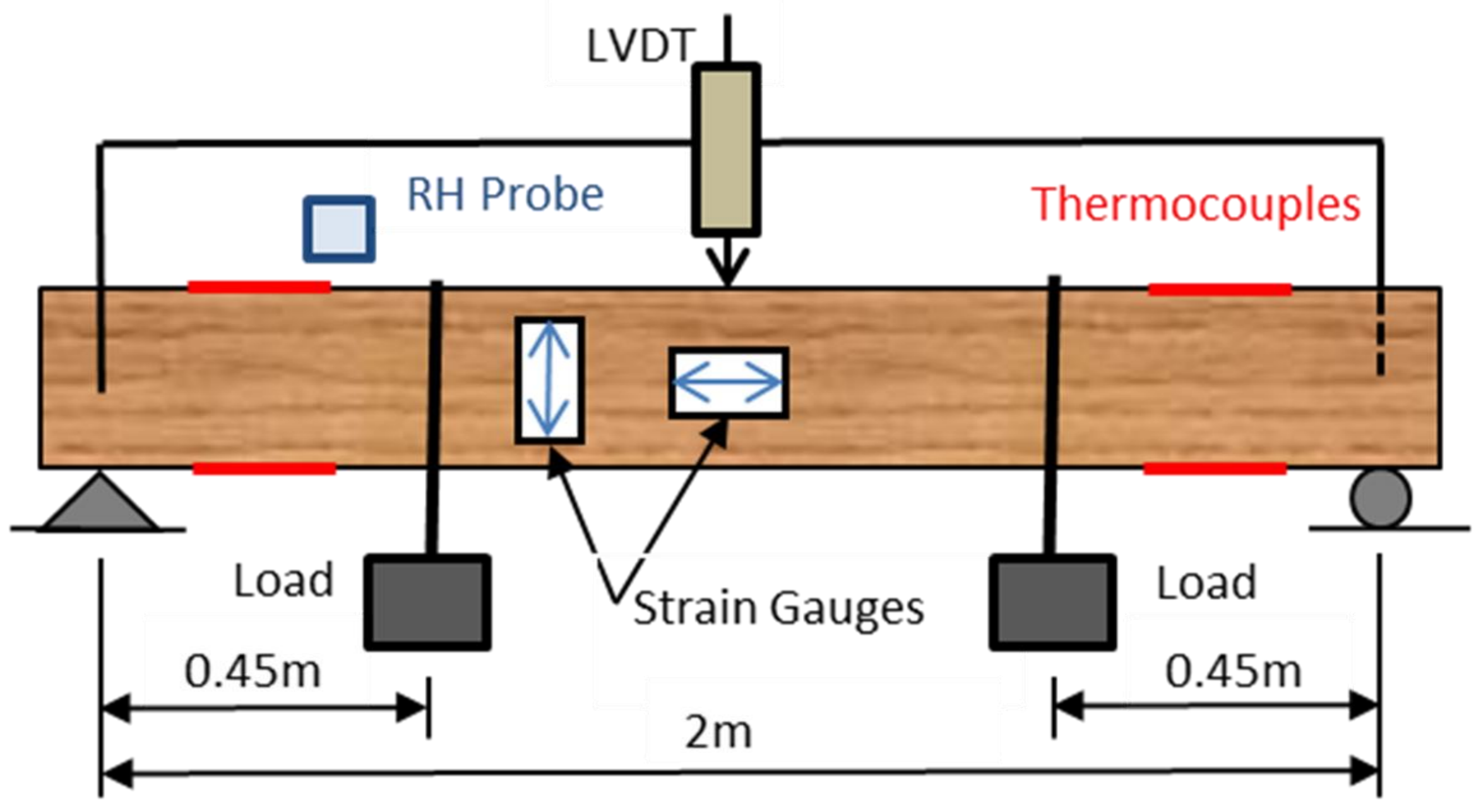
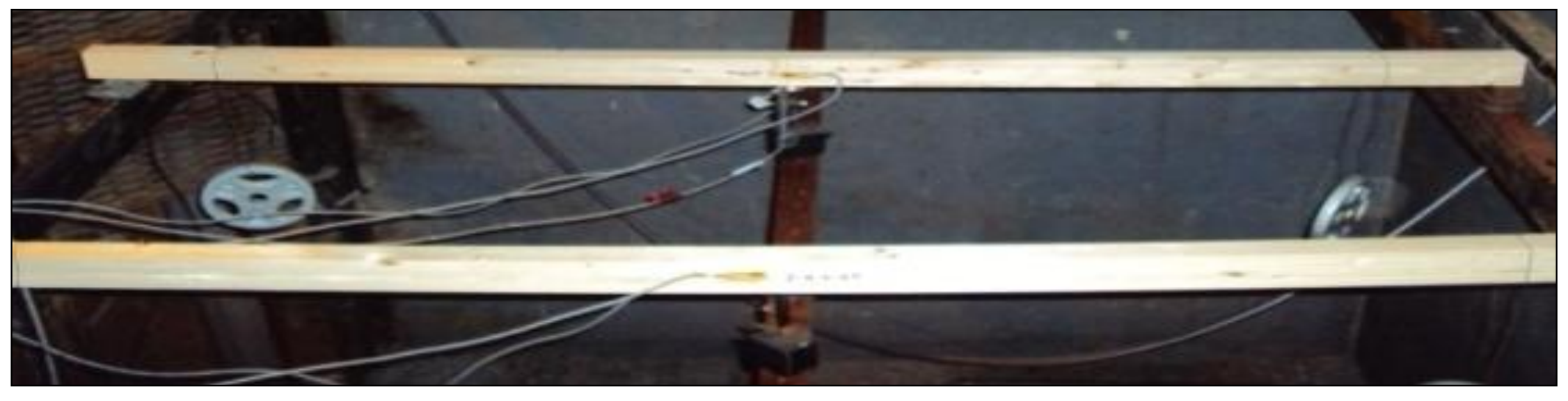


Figure 3: Loaded test arrangement - schematic with respect to strain gauge positions

Two control specimens were kept in the constant environment (i.e. 12% *EMC*) and the six others were tested in a specially built environmental chamber. The special chamber has the capability to alter the climate (*T* and *RH*) of air surrounding specimens while they were supported in different ways and/or subjected to effects of external loads as illustrated in figure 4 below.

(a) Unloaded Glulam beam



(b) Loaded test arrangements in the variable climate

Figure 4: Experiment set up in Laboratory

Table 1. Lists the combinations of test conditions investigated

Specimens	Loaded	Climate
ULC1, ULC2	No	Constant*
LC1, LC2	Yes**	Constant
ULV1, ULV2	No	Variable
LV1, LV2	Yes	Variable

*20°C, 65% RH, ** As in figure 3*

MODELLING DESCRIPTION

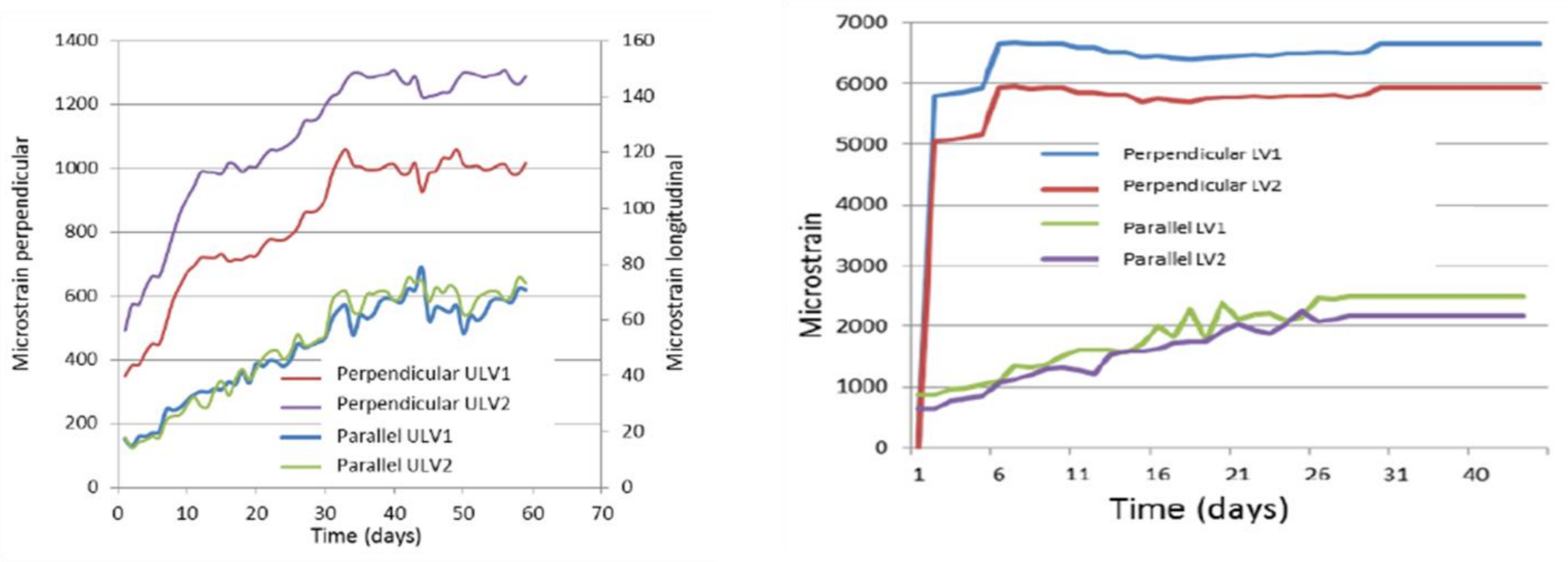
The ABAQUS finite element software package was used as the modelling medium for coupled mass diffusion analysis, consisting of a coupled temperature-displacement analysis followed by a mass diffusion analysis. ABAQUS was selected because it can perform sequentially coupled thermo-mechanical mass diffusion analysis. Material properties were selected based on assuming a three-dimensional rectilinear orthotropic material structure. Diffusivity of mass was assumed to be the same in longitudinal and transverse directions.

C3D8T eight-node linear hexahedron thermally coupled brick elements were used to model the scaled glulam members with tri-linear displacement and temperature variations for coupled displacement and temperature analyses, with 4800 elements in total. These elements were selected to exploit the similarity of governing equations for temperature and moisture transport, which enabled the governing constant for a temperature field to be replaced by the effective coefficient of diffusion for mass transport.

LABORATORY RESULTS

As shown in figure 6(a) and (b) below for both specimens loaded and un-loaded the following observations can be drawn out.

- There was an increase of strain for unloaded glulam beam due to variation of relative humidity in the chamber.
- The increase of strain was even much higher in the combination of loaded beams and varying relative humidity, this is due to the fact that other two mechanism are included which is elastic creep and mechanosoptive creep.



(a) Unloaded beams (b) Loaded beams

Figure 5 : Experimental results

FINITE ELEMENT RESULTS

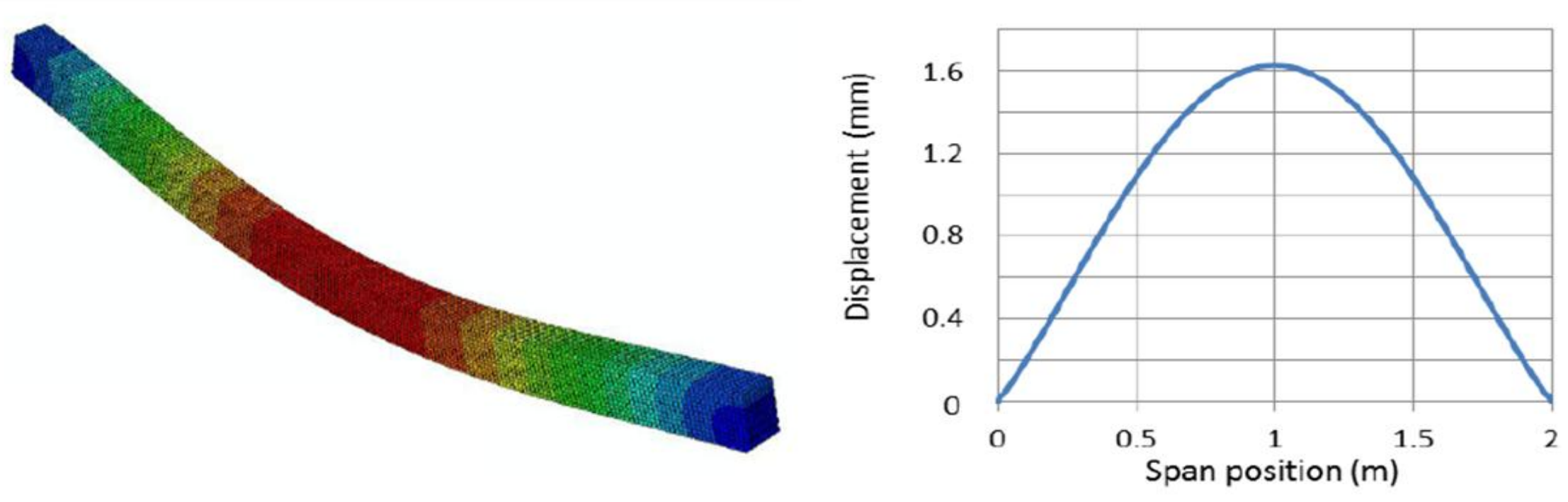
The results were obtained from Abaqus with user subroutine that was provided by international collaborators to be able to obtain total strain as shown in the equation below:

$$\varepsilon_{total} = \varepsilon_e + \varepsilon_t + \varepsilon_u + \varepsilon_{ms} + \varepsilon_{cr}$$

where

ε_{total} = Total strain, ε_e= Elastic strain,
ε_t = Thermal strain, ε_u= Moisture strain,
ε_{ms}= Mechanosoptive strain, ε_{cr} = Creep strain

Figure 6(a) &(b) shows typical predicted surface strains and deflection shapes, for a loaded specimen in a variable climate respectively.



(a) Predicted responses after loading (b) Bending displacement due to self weight & external loading

Figure 6. Finite element results due to self weight and external loading

Figure 7. below shows the strain that was obtained from finite element modelling. As it can be observed there was a good agreement with laboratory results though the model still need more refinement.

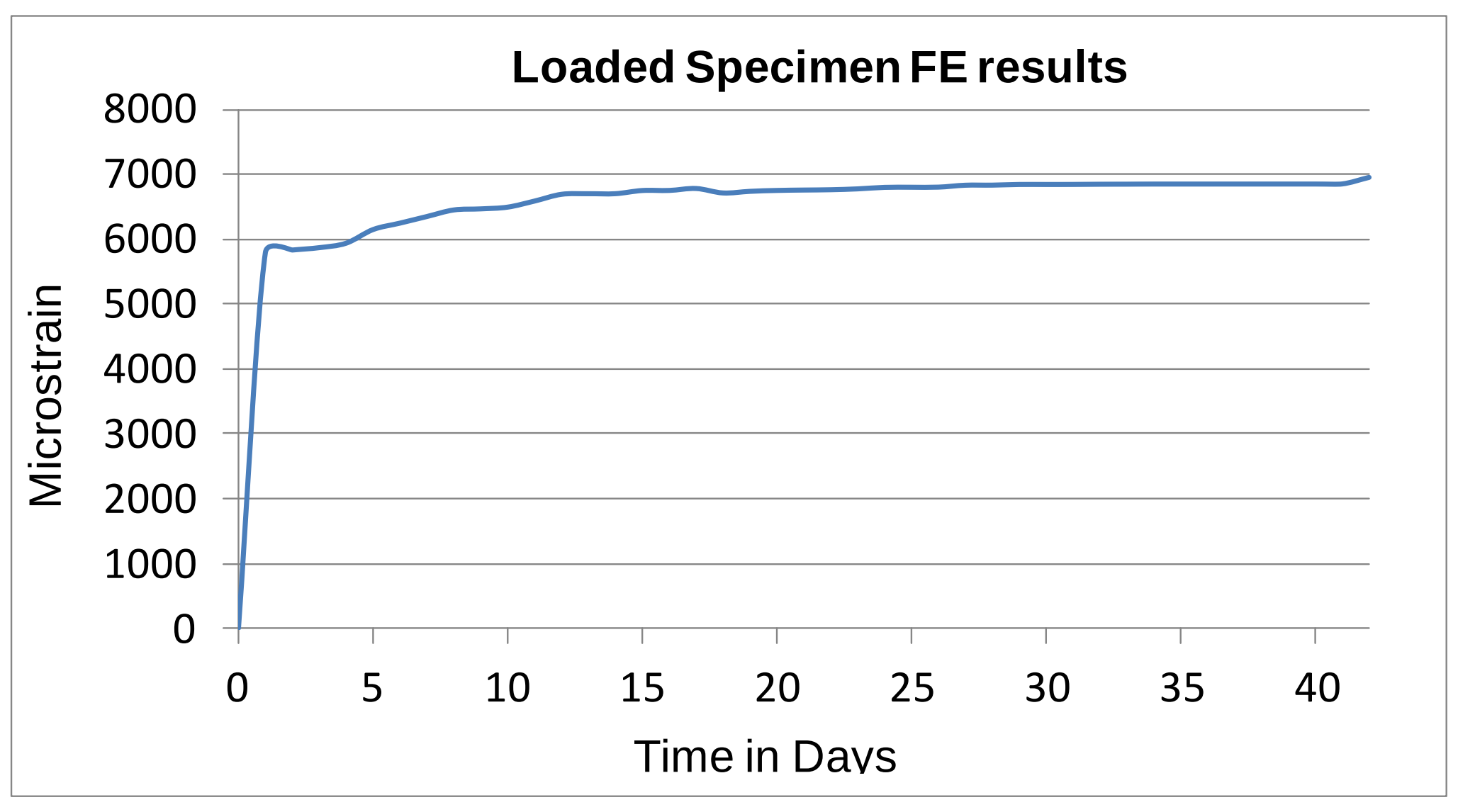


Figure 7. Surface strain obtained from FE prediction.

DISSCUSSION

As shown in figure 7. above there was a good agreement between laboratory tests and FE modelling predictions. This provides confidence to continue to use the FE modelling technique together with experiments to study more complex systems such as connections, and to investigate and to predict combined movement due to loading and moisture variations.

CONCLUSIONS

Even though what has been done so far by the authors and other pioneers is limited, it is clearly feasible to predict temporally varying internal strains and external deformations of drying or wetting glulam structural components via continuum finite element modelling techniques. The employed framework of sequentially-coupled three-dimensional hydrothermal modelling shows promise as the basis of a robust engineering tool for predicting, and therefore being able to counteract, adverse deformations and material incompatibilities that can exist within hybrid building systems.

ACKNOLEDGEMENT

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