Numerical and experimental investigation on the behavior of wood-composite T joints

M. Arnesano, V. Dattoma, R. Nobile, W. Panella
Università del Salento, Dipartimento di Ingegneria dell'Innovazione, Via per Arnesano - 73100 Lecce
marco.arnesano@unisalento.it, vito.dattoma@unisalento.it, riccardo.nobile@unisalento.it, francesco.panella@unisalento.it

ABSTRACT. The aim of this study is the evaluation of mechanical behaviour of T-joints made in wood and reinforced with bidirectional long glass fiber and epoxy matrix, using numerical and experimental methods of investigation. Joints in composite / wood are not uniform and different interfaces are present in them, each of which responds differently over time when requested. These composites are also anisotropics and many important mechanical quantities, such as stiffness, vary independently of each other. Due to the characteristic heterogeneity of constituent materials, the diversity of the thickness [1,2,3], the characteristic loading mode, the study of these composites is very complex to be analyzed. The difficulty in developing analytical models able to interpret and to predict their behaviour over time, is complicated by the different phenomena interacting with each other. Obtaining coherent results from numerical-experimental methods of investigation, therefore, means having an ideal instrument to study and monitor the evolution of damage [4,5]. In this work, a numerical FEM model of a simple T-joint has been developed in order to evaluate stress field in the critical point. Finally, experimental static tests are carried out on the same kind of joints.

INTRODUCTION

In the last years, improvements in wood technology, in particular the introduction of epoxy resins, confer to this material new possibilities in industrial application. In nautical, for example, joints wood / composite are important and widely diffuses. However, joint technology represents an aspect to be developed, since they represent a potentially weak area from a structural point of view.
Moreover, the composite materials are characterized by the presence of defects, micro cavity, air inclusions, delamination and so on. Defect could occur during the manufacturing process of the component, during the commissioning or for the incompatibility of the elements to join.
The study of these composites is very complex to be analyzed. The difficulty in developing analytical models able to interpret and to predict their behaviour over time, is complicated by the different phenomena interacting with each other.
In fact, while the propagation of a crack / defect and fatigue in homogeneous and isotropic materials follows laws that, opportunely corrected with experimental coefficients, can be considered reliable (Law of Paris, the Wöhler curve), in fibrous- reinforced materials a true difficulty in achieving this objective exists, since the damaging phenomena are interacting.
In this job several tests have been conducted on T joints subjected to static bending on three points.
The obtained results have been analyzed and compared with those obtained by appropriate numerical models developed by FEM analysis on ANSYS code.

The Figure 1 shows a typical T-joint. It consists of horizontal and vertical wooden panels joined together by an angle laminate reinforcement. The junction between the two panels is made by laminating reinforced strips of glass woven on both sides in order to form a double angle connection.

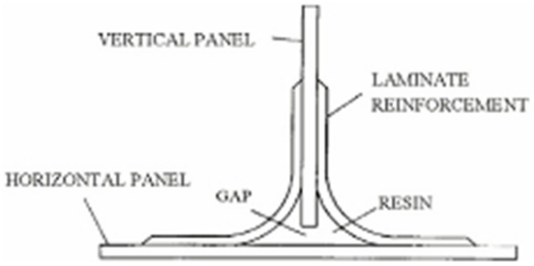

Figure 1: Typical T-joint.

The resulting gap is then filled with an epoxy resin, compatible with the reinforced woven and with the material of the joint panels. Generally, the wood powder is also taken into resin to reduce weight.

EXPERIMENTAL ANALYSIS

Static three-points bending have been carried out on six T joints specimens.
The joints are composed of:
- horizontal panel in african mahogany of two different thicknesses: 3 and 5 mm,
- vertical marine plywood panel in standard thickness of 6 mm,
- superior laminate reinforcement in woven biaxial fiber-glass ± 45° on both panels, for a length of 70 mm,
- inferior laminate reinforcement in woven biaxial fiber-glass 0-90° along the entire length of the panel,
- SP 106 epoxy system (A resin + B slow hardener) in the 5:1 ratio.

Figure 2: Wood-composite T-joint specimens.

Specimens have a width of about 60 mm, a length of 300 mm and a height of the vertical panel of 150 mm.
The test machine is the electro-mechanic INSTRON 4500 having a load capacity of 200 kN, equipped with two supports that can slide along a horizontal guide, allowing to adjust the span length before the tests. In particular span lengths of 230, 152 and 88 mm are used. During test, applied load and crosshead travel have been recorded.
In Tab. 1, test data and failure mode is reported for each specimen.
Fig. 3÷5 reported the test results, expressed in terms of applied load divided by specimens width. Each Figure is referred to a specific value of span length.
The failure occurred at relevant values of load and in correspondence of high vertical displacements, showing the good reliability of the joining technique.

HORIZONTAL PANEL HEIGHT: 5 mm		
Test 4B	Test 2B	Test 1B
Thickness: 58 mm Height panel / reinforce: 6 mm Supports distance: 230 mm Failure of fibers stretched on the horizontal panel. Delamination of laminate reinforcement.	Thickness: 59 mm Height panel / reinforce: 6 mm Supports distance: 152 mm Failure of fibers stretched on the horizontal panel.	Thickness: 59 mm Height panel / reinforce: 6 mm Supports distance: 88 mm Failure of fibers stretched on the horizontal panel.
HORIZONTAL PANEL HEIGHT: 5 mm		
Test 4A	Test 2A	Test 1A
Thickness: 60 mm Height panel / reinforce: 5 mm Supports distance: 230 mm Failure of fibers stretched on the horizontal panel.	Thickness: 58 mm Height panel / reinforce: 5 mm Supports distance: 152 mm Failure of fibers stretched on the horizontal panel. Delamination of laminate reinforcement.	Thickness: 58 mm Height panel / reinforce: 5 mm Supports distance: 88 mm Failure of fibers stretched on the horizontal panel. Horizontal panel delamination.

Table 1: Test data and failure mode for each specimen.

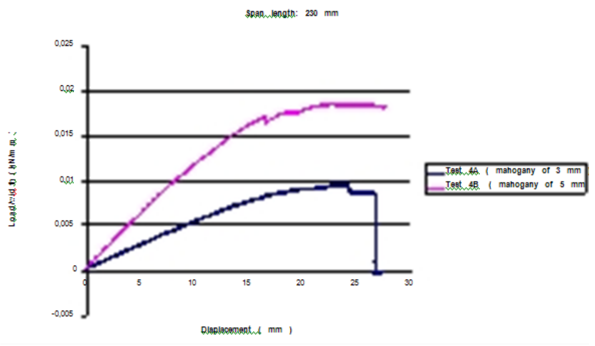

Figure 3: Test results expressed in terms of applied load divided by specimens width for span length 230 mm.

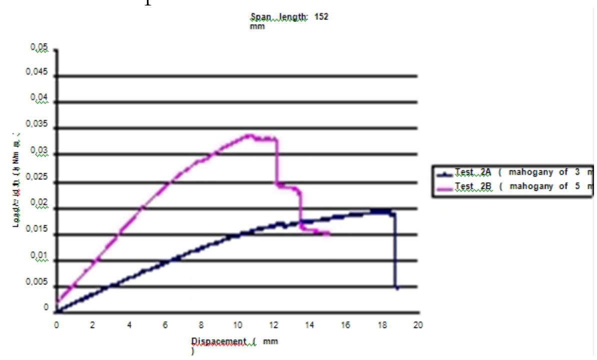

Figure 4: Test results expressed in terms of applied load divided by specimens width for span length 152 mm

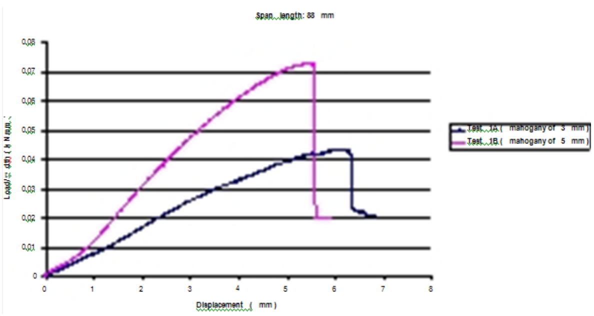

Figure 5: Test results expressed in terms of applied load divided by specimens width for span length 88 mm.

FEM ANALYSIS

In order to compare results obtained by test carried out with different span length, a FEM analysis using ANSYS code are carried out to determine stress state.

Different models were built considering different thickness for the horizontal panel: 3 or 5 mm. Finally, various simulations were executed varying the span length.

The horizontal panel, vertical panel and intermediate gap has been modelled with solid elements SOLID186; the reinforcement constituted in epoxy SP 106 and glass fiber has been modelled with SHELL91 elements suitable for modelling thin structures.

For the horizontal mahogany panel and the laminate reinforcement, the material was considered orthotropic in the direction of strength of wood or fiber-glass.

The material characteristics prescribed in the model are [6]:

Horizontal african mahogany panel	Vertical marine plywood panel	Laminate reinforcement composed of epoxy system 106 + SP fiber-glass	Intermediate gap composed of epoxy system + wood powder
$E_{\backslash\backslash\ fiber} = 9500\ N/mm^2$	$E_{isotropic} = 7500\ N/mm^2$	$E_{\backslash\backslash\ fiber} = 20500\ N/mm^2$	$E_{isotropic} = 375\ N/mm^2$
$E_{\perp\ fiber} = 1400\ N/mm^2$	$\nu = 0.3$	$E_{\perp\ fiber} = 5552\ N/mm^2$	$\nu = 0.25$
$G_{fiber\ plane} = 3653\ N/mm^2$		$G_{fiber\ plane} = 2068\ N/mm^2$	
$G_{\perp\ fiber} = 538\ N/mm^2$		$G_{\perp\ fiber} = 1316\ N/mm^2$	
$\nu = 0.3$		$\nu = 0.3$	

Table 2: Material characteristics.

A vertical load equal to the maximum load experimentally measured before failure has been applied on the model to compare the numerical deformation obtained with the experimental ones.

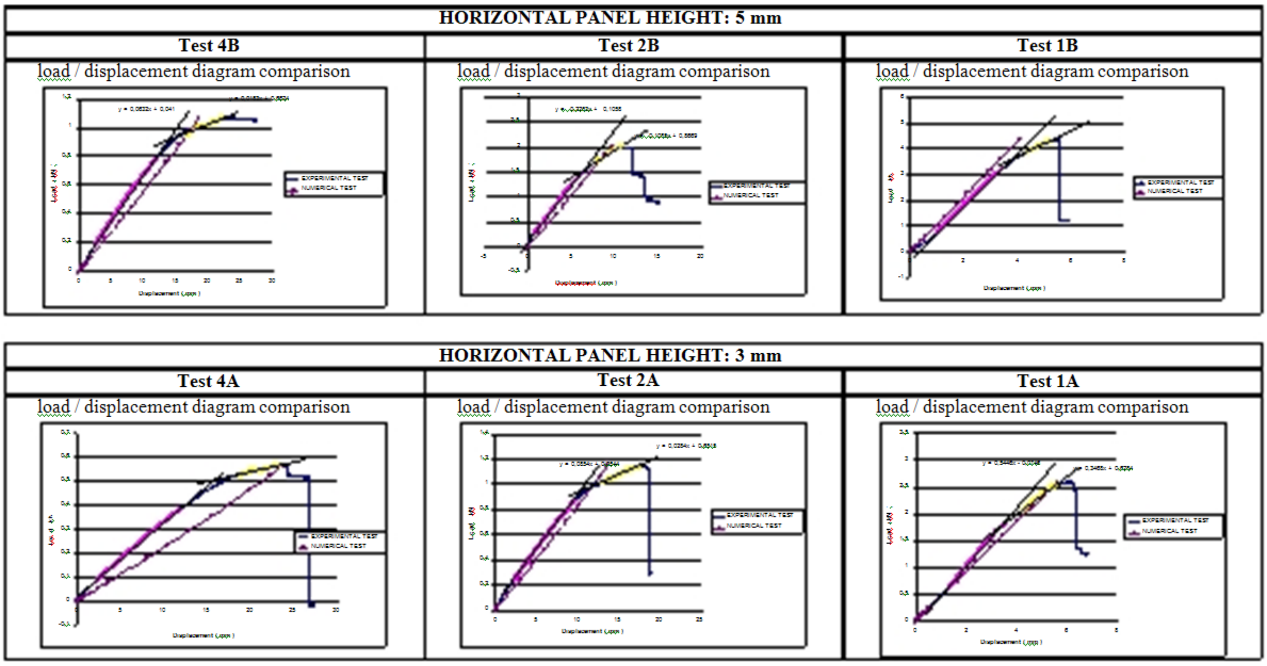

Figure 5: Numerical and experimental deformation comparison.

It can be noticed that the numerically values are comparable with the experimental results. At least in the linear behaviour, there is a similar trend of the characteristic load / displacement.
Figure 5 reported the comparison of numerical and experimental behaviour of each test, showing the reliability of the FEM model.

CONCLUSION

A series of three-points bending tests has been carried out on wooden T-joint specimen, in order to validate the joining technique.
As a first result, the set-up of a numerical model of the T-joint has been successfully compared to experimental test.

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