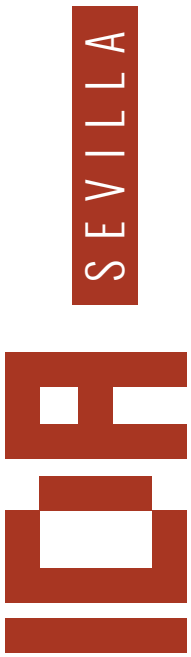
SEVILLA

IDA: ADVANCED DOCTORAL RESEARCH IN ARCHITECTURE



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Antonio Tejedor Cabrera, Marta Molina Huelva (comp.)

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EDITOR
Universidad de Sevilla

COMPILERS
Antonio Tejedor Cabrera
Marta Molina Huelva

DESIGN AND LAYOUT BY
Pablo Blázquez Jesús
María Carrascal Pérez
Daniel Longa García
Marina López Sánchez
Francisco Javier Navarro de Pablos
Gabriel Velasco Blanco

ADMINISTRATION AND SERVICES STAFF
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FORMATO

Mesas temáticas
Las mesas temáticas son lugares de presentación de las metodologías y las experiencias de jóvenes doctores y de estudiantes de doctorado procedentes de las diferentes universidades. Son gestionadas por los propios estudiantes de doctorado que generan unas conclusiones para ser debatidas y reelaboradas en la sesión plenaria final. Las sesiones se desarrollan de manera simultánea con la presentación de los *papers* seleccionados en la *call*, organizados en cuatro áreas o líneas temáticas:

1. Tecnologías de la Arquitectura
2. Vivienda, Ciudad y Territorio
3. Patrimonio y Rehabilitación
4. Análisis y Proyectos Avanzados

Taller
El workshop del Congreso se orienta hacia el análisis de los problemas y las necesidades de gestión de los Programas de Doctorado con el fin de extraer conclusiones que pueden ser útiles a las Universidades implicadas. En el workshop participan los coordinadores de los programas de Doctorado en Arquitectura y los representantes de los doctorandos. Son temas de debate: las líneas de investigación, las metodologías, las necesidades organizativas de los programas de doctorado, el Doctorado Internacional y el Doctorado Industrial, y el futuro de la investigación doctoral.

Sesiones Plenarias
Las sesiones plenarias se realizan al inicio y al final del Congreso. En la primera sesión de bienvenida e introducción al Congreso se invita a participar a expertos investigadores del panorama nacional e internacional y a los coordinadores de los programas de doctorado. En la segunda sesión plenaria se propone un debate abierto para la reelaboración de las propuestas extraídas del taller y de las mesas temáticas. Sirve también de clausura con la presentación de las conclusiones finales del Congreso IDA_Sevilla 2017.

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FOREWORD

The Instituto Universitario de Arquitectura y Ciencias de la Construcción (IUACC), in collaboration with the Escuela Técnica Superior de Arquitectura (ETSAS) and the Escuela Internacional de Doctorado (EIDUS) of the University of Seville are pleased to welcome the heads of research from both Spanish and overseas universities, consolidated researchers and young doctoral researchers to the First International Congress of Doctorates in Architecture IDA Sevilla, from 27th to 28th November 2017.

The **IDA_Sevilla 2017** Congress offers a general perspective of doctoral studies in the field of Architecture and its related disciplines: urban planning, heritage, landscape, construction technologies and sustainability. In the new context generated after the elimination of the doctoral programs prior to RD 99/2011, it is necessary to carry out an analysis of the complex panorama that the former programs and the new doctoral programs have drawn up, in order to know in detail both what has been achieved so far, as well as the challenges of the future of advanced doctoral research in Spain, in the European and international context.

The startling changes that are taking place in our society call for a vision of research that is not compartmentalised into traditional disciplines or areas of knowledge. Doctoral research in Architecture must adapt to changes in society and to the sustainable productive needs of territory.

The congress will take place at the Escuela Técnica Superior de Arquitectura de Sevilla, organised in four simultaneous thematic tables, a workshop on the administration of doctoral programs and two plenary sessions.

The **thematic tables** are aimed at young doctors and doctoral students of the different participating universities who will present their experiences and methods of their research - in development or recently concluded. The participation in the thematic tables is carried out through the selection procedure with blind peer review established in the call for papers and through express invitations to the debate. The almost 70 communications have been structured in four thematic areas representative of the PhD programs in Architecture.

The **open workshop** will be held in two sessions with the participation of the coordinators of each of the collaborating programs of the Congress, and professors with extensive doctoral experience. Its objectives are multiple: to discuss the experiences undertaken in the different universities, exchange ideas about the approaches and models applied, address the challenges of internationalization and management, launch the new Industrial Doctorate with companies and public agencies, and so on.

There are two **plenary sessions**: one, a plenary session of introduction to the congress, with the participation of coordinators of national and foreign doctoral programs; and a closing plenary session, with an open debate for the going-over of the conclusions drawn from the thematic tables and the workshop, and the presentation of final conclusions.

We thank the Escuela Internacional de Doctorado of the University of Seville, and the Escuela Técnica Superior de Arquitectura de Sevilla for the support they have provided for the holding of this meeting, which contributes so much to the clarification of the future of doctoral studies in Spanish universities in the face of the great challenge of internationalization and the continuous improvement of the quality of research in Architecture. We also thank those responsible for the participating Doctoral Programs, the Architecture library of the US and all the participants and attendees.

Antonio Tejedor Cabrera
Marta Molina Huelva

Conference Chairpersons IDA_Sevilla 2017
Instituto Universitario de Arquitectura y Ciencias de la Construcción IUACC

PRÓLOGO

El Instituto Universitario de Arquitectura y Ciencias de la Construcción (IUACC), con la colaboración de la Escuela Técnica Superior de Arquitectura (ETSAS) y la Escuela Internacional de Doctorado (EIDUS) de la Universidad de Sevilla, se complacen en recibir a los responsables de investigación de universidades españolas y extranjeras, a los investigadores consolidados y a los jóvenes investigadores de doctorado en el I CONGRESO INTERNACIONAL DE DOCTORADOS EN ARQUITECTURA IDA_Sevilla, del 27 al 28 de noviembre de 2017.

El congreso **IDA_Sevilla 2017** ofrece una perspectiva general de los estudios de doctorado en el campo de la Arquitectura y sus disciplinas afines: urbanística, patrimonio, paisaje, tecnologías de la construcción y sostenibilidad. En el nuevo contexto generado tras la extinción de los programas doctorales anteriores al RD 99/2011 es necesario realizar un análisis del complejo panorama que han construido los programas extintos y los nuevos programas de doctorado, con el objeto de conocer con detalle tanto lo conseguido hasta ahora como los retos que depara el futuro de la investigación doctoral avanzada en España, en el contexto europeo e internacional.

Los vertiginosos cambios que se están produciendo en nuestra sociedad reclaman una visión de la investigación no compartimentada en disciplinas o áreas de conocimiento tradicionales. La investigación doctoral en Arquitectura debe adaptarse a los cambios de la sociedad y a las necesidades productivas sostenibles en el territorio.

El congreso se celebra en la Escuela Técnica Superior de Arquitectura de Sevilla organizado en cuatro mesas temáticas simultáneas, un taller sobre la gestión de los programas de doctorado y dos sesiones plenarias.

Las **mesas temáticas** están dirigidas a los jóvenes doctores y a estudiantes de doctorado de las diferentes universidades participantes que exponen sus experiencias y métodos sobre las investigaciones en desarrollo o recientemente concluidas. La participación en las mesas temáticas se realiza por el procedimiento de selección con revisión por pares ciegos establecido en la *call for papers* y por medio de invitaciones expresas al debate. Las casi 70 comunicaciones se han estructurado en cuatro áreas temáticas representativas de los programas de doctorado en Arquitectura.

El **taller** de puesta en común se realiza en dos sesiones con la participación de los coordinadores de cada uno de los programas colaboradores del Congreso y de profesores con amplia experiencia doctoral. Sus objetivos son múltiples: debatir sobre las experiencias desarrolladas en las distintas universidades, intercambiar ideas sobre los enfoques y los modelos aplicados, abordar los retos de internacionalización y de gestión, poner en marcha el nuevo Doctorado Industrial con empresas y agencias públicas, etc.

Las **sesiones plenarias** son dos: una sesión plenaria de introducción al congreso, con la intervención de coordinadores de programas de doctorado nacionales y extranjeros; y una sesión plenaria de clausura, con un debate abierto para la reelaboración de las conclusiones extraídas de las mesas temáticas y del workshop y la presentación de las conclusiones finales.

Agradecemos a la Escuela Internacional de Doctorado de la Universidad de Sevilla y a la Escuela Técnica Superior de Arquitectura de Sevilla el apoyo que han proporcionado para la realización de este encuentro que tanto contribuye a clarificar el futuro de los estudios doctorales en las universidades españolas ante el gran reto de la internacionalización y la continua mejora de la calidad de la investigación en Arquitectura. Damos los gracias también a los responsables de los Programas de Doctorado participantes, a la Biblioteca de Arquitectura de la US y a todos los participantes y asistentes.

Antonio Tejedor Cabrera
Marta Molina Huelva

Directores Congreso IDA_Sevilla 2017
Instituto Universitario de Arquitectura y Ciencias de la Construcción IUACC

OBJECTIVES

1. Analyze the research lines of the various programs and build a map of doctoral research in Spain with the support of coordinators, tutors / thesis supervisors, doctoral students and young doctors in the disciplines related to Architecture and their related areas.

2. To know the status of doctoral theses in progress or defended in the last three years, selected by means of a call with blind peer evaluation of the doctoral programs participating in the congress.

3. Discuss the structure and university management of doctoral programs in relation to employment challenges, collaboration with the productive sector and national research programs.

4. Exchange experiences with other international doctoral research programs on international mobility management, theses with international mention, co-supervised theses, theses with industrial mentions, etc.

5. No less important, consolidate a national and international network of Doctoral Programs related to Architecture, Urban Planning, Heritage, Landscape, Technologies and related disciplines.

IDA ADVANCED DOCTORAL RESEARCH SEVILLA 2020

LT 1 ARCHITECTURE TECHNOLOGIES

LT 2 HOUSING, CITY AND TERRITORY

LT 3 HERITAGE AND REHABILITATION

LT 4 ANALYSIS AND ADVANCED PROJECTS

FORMAT

Thematic tables
The thematic tables are places to present the methodologies and experiences of young doctors and doctoral students from different universities. They are managed by the doctorate students themselves, who generate conclusions to be debated and reworked in the final plenary session. The sessions are developed simultaneously with the presentation of the papers selected in the call, organized in four areas or thematic lines:

1. Architectural technologies
2. Housing, city and territory
3. Heritage and Rehabilitation
4. Analysis and advanced projects

Workshop
The workshop of the Congress is oriented towards the analysis of the problems and management needs of the Doctorate Programs, with the objective of arriving at conclusions that may be useful to the Universities involved. The coordinators of the Doctorate in Architecture programs and the doctoral students' representatives will participate in the workshop. The following are topics for debate: lines of research, methodologies, organizational needs of the doctoral programs, the International Doctorate and the Industrial Doctorate, and the future of doctoral research.

Plenary Sessions
The plenary sessions are held at the beginning and end of the Congress. In the first session of welcome and introduction to the Congress, researchers from the national and international scene and the coordinators of the doctorate programs are invited to participate. In the second plenary session an open debate is proposed for the going over of the proposals drawn from the workshop and the thematic tables. It also serves as a closing ceremony with the presentation of the final conclusions of the 2017 IDA_Sevilla Congress.

Beams were tested in bending, according to UNE-EN 408 (2011) (Fig.6), and the effects of GFRP reinforcements in the MOE, ultimate strength (MOR) and improvement in the dispersion of results were measured and analyzed. The failure modes of each beam were also observed.

Fig. 6 Duo beams test according to UNE EN-408.

The results of these tests on reinforced Populus beams are shown in Figure 7, with a significant improvement with increments in the moduli of elasticity of 10% for GFRP reinforcements of 1200 gr / m2 and of around 15% for GFRP reinforcements of 2400 gr / m2.

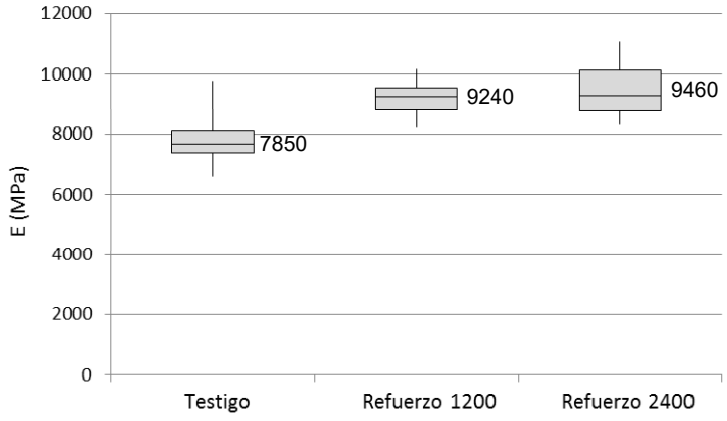

Fig. 7 Box and whiskers graph with the modulus of elasticity of poplar duo beams.

At the present time only the previous data analyzes of the poplar duo beams are available, and the bending test of the Pinaster beams is scheduled for close dates.

3.3. Creep tests

In order to study the long-term behavior of the reinforced duo beams, in relation to unreinforced ones, a long-term test has been set up, according to UNE-EN 380 (1998), with a total load of 10 kN, which represents approximately 50% of ultimate load of the beams. The ambient conditions of the laboratory remain nominally constant, 20 ± 2ºC; 65 ± 5% humidity in air, corresponding to a hygroscopic balance of 12% HR in the wood (Kollman 1959).

The load is applied by means of the filling and filling of individual tanks (Figure 8), single wall polyethylene (PE), with a useful capacity of 1000 liters and dimensions of approximately 1650x720x1260 mm, with upper filling nozzles and lower emptying device, with locking key. The support of the tanks on the beams is made with an intermediate resistant platform, which allows to apply the load on the beams on two points, following the support distances proposed by UNE-EN 408 (2011).

OBJETIVOS

1. Analizar las líneas de investigación de los diversos programas y construir el mapa de la investigación doctoral en España con el apoyo de los coordinadores, los tutores/directores de tesis, los doctorandos y los jóvenes doctores en las disciplinas relacionadas con la Arquitectura y sus áreas afines.

2. Conocer el estado de las tesis doctorales en marcha o defendidas en los últimos tres años, seleccionadas por medio de una *call* con evaluadores por pares ciegos de los programas de doctorado participantes en el congreso.

3. Debatir sobre la estructura y la gestión universitaria de los programas de doctorado en relación con los retos de empleo, colaboración con el sector productivo y los programas nacionales de investigación.

4. Intercambiar experiencias con otros programas de investigación doctoral a escala internacional sobre gestión de la movilidad internacional, tesis con mención internacional, tesis en cotutela, tesis con mención industrial, etc.

5. No menos importante, consolidar una red nacional e internacional de Programas de Doctorado relacionados con la Arquitectura, la Urbanística, el Patrimonio, el Paisaje, las Tecnologías y sus disciplinas afines.

IDA INVESTIGACIÓN DOCTORAL AVANZADA

LT 1 TECNOLOGÍAS DE LA ARQUITECTURA

LT 2 VIVIENDA, CIUDAD Y TERRITORIO

LT 3 PATRIMONIO Y REHABILITACIÓN

LT 4 ANÁLISIS Y PROYECTOS AVANZADOS


IDA
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LT 1

TECNOLOGÍAS DE LA ARQUITECTURA

ARCHITECTURE TECHNOLOGIES / TECNOLOGÍAS DE LA ARQUITECTURA

FRP REINFORCEMENT AND PRODUCTION OF DUO TIMBER BEAMS

Balmori, Jose Antonio [(1)(*)] and Basterra, Luis-Alfonso [(1)]

(1) Recognized Research Group on Timber Structures and Wood Technology. University of Valladolid.
(*)balmori@arq.uva.es

Abstract: The main objective of this research is to give a new use and added value to fast growing and low cost economic woods from Castilla y León, such as Populus x euroamericana I-214 and Pinus pinaster Ait. Making an industrialized material (reinforced duos beams) competitive in mechanical properties and costs with other products of industrialized wood commercialized today.The research includes the methodology followed and partial results achieved in the fabrication of witnesses and reinforced duo beams of Populus x euroamericana I-214 and Pinus pinaster Ait. wood, with rigid bands of fiberglass (GFRP). The results obtained in previous tests of selection of reinforcing fibers, epoxy adhesives and superficial treatments of the rigid bands GFRP are shown. Initially, flexural tests were carried out with medium density fiberboard (MDF) duo beams in order to eliminate wood variability, reaching increments in the modulus of elasticity of 26-38%. In the final tests on wooden duo beams the results showed improvements of 10-15% in modulus of elasticity, reaching in the reinforced duo beams similar values to commercial laminated wood. Also, long-term creep tests were performed at low load levels comparing the behavior of non-reinforced duo beams and GFRP-reinforced duo beams.

Keywords: Structural reinforcement, Timber, Duo beam, Polymer reinforced with fibers (FRP), Composite systems.

1. Introduction

Reinforcing timber structures in service with Fiber Reinforced Polymers (FRP) materials is a well-known technique, extensively developed in the literature (Barkis et al 2002). However, direct applications of FRP to commercial wood products for new structures (Parvez 2004) are limited to few cases. Based on previous work (Theakston 1965, Bulleit 1984, Schober et al 2015), this research focused on the improvement and enhancement of fast-growing, low-cost, low-strength timber, through the incorporation of internal FRP reinforcements. For this purpose, we produced and tested reinforced duo laminated beams, with timber from species such as poplar (*Populus x euroamericana* I-214) and maritime pine (*Pinus pinaster* Ait.), which are currently only designated for non-structural purposes in Spain.

Laminated duo beams were used, as they represent the most basic system of industrialization. The GFRP reinforcement was introduced into the glue line, protected from fire action and atmospheric agents (Martin et Tingley 2000). This also allowed for different widths of reinforcement, without any visual impact (Fig. 1).

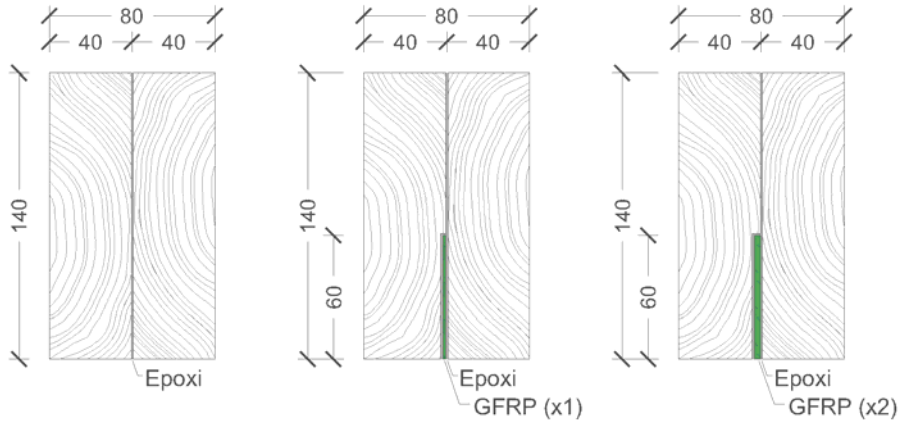

Fig. 1 Provision of reinforcements and dimensions of the tested beams.

2. Methods

The use of different types of FRP reinforcements, adhesives and the amount of reinforcement used to increase the rigidity of the pieces and to homogenize their mechanical performance, at commercially competitive costs, were studied. A selection and characterization of the different materials (wood, FRP, adhesives) were carried out through different test campaigns (Table 1)

Table 1. Testing program.

Test	Standard
FRP fibers (CFRP, BFRP, GFRP)	ASTM D2256-02
Adhesives (poliuretanos, epoxi,…)	UNE-EN 56543:1988
Duo beams DM+FRP (Scale 1:4)	UNE-EN 408:2011
GFRP rigid bands	ISO 527-5:2010
Populus duo beams (Escala 1:2)	UNE-EN 408:2011
Pinaster duo beams (Escala 1:2)	UNE-EN 408:2011
Delamination tests	UNE-EN 302:2013
Creep tests	UNE-EN 380:1998

2.1. Timber used

The timber used in the manufacture of test specimens belongs to the species Populus x euroamericana I-214 and Pinus pinaster Ait., both coming from Castilla y León forests. Basic characteristics of tested wood are shown in Table 2:

Table 2. Mechanical properties of wood.

Timber	Young module (GPa)	Last tension (MPa)
Populus x euroamericana I-214	7.83 (10.18*)	36.02 (25.51*)
Pinus pinaster Ait	11.01 (14.77*)	54.75 (25.41*)

* COV% .

These trees species spread throughout the plateau resulting from reforestation policies; concentrating the poplar in the rivers banks and the pinaster in arid zones. At the moment these wood resources are destined primarily for first transformation industrial uses with low economic values.

2.2. Selection and characterization of fibers (FRP)

The first phase of the research focused on the testing and characterization of some fibers, incorporating in the study both natural fibers and high modulus synthetic fibers. Tensile tests were performed, according to ASTM D2256-02 (2002), to obtain the elasticity moduli of each material, and a comparison was drawn between their mechanical performance and their cost. As It is showed in figure 2, the natural fibers did not have the mechanical properties necessary to significantly reinforce of the beams. Within the high-modulus synthetic fibers two performance steps can be observed; carbon fibers and the rest (fiberglass, basalt fiber, ...).

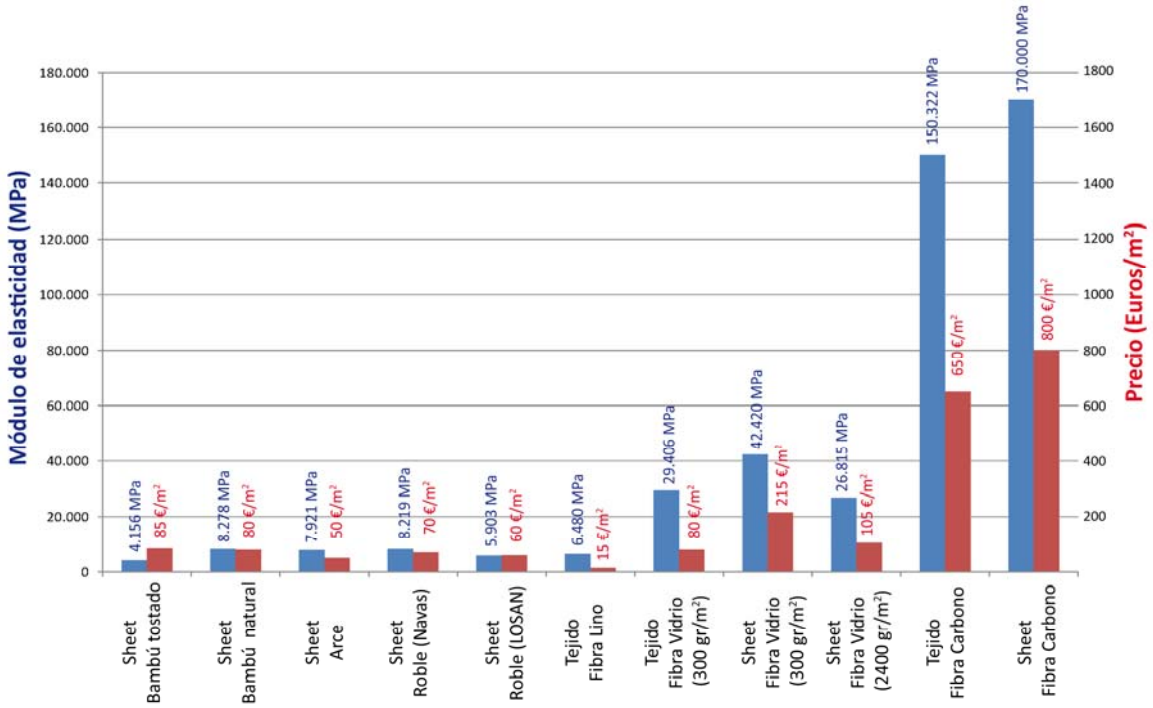

Fig. 2 Comparison between modulus of elasticity and price of the different fibers tested.

Among the analyzed fibers, 3 types were chosen for duo beam witnesses fabrication: FIDFLAX UNI 300 HS 50, FIDGLASS UNI 300 HT 73 and SIKAWRAP-203 C / 45. A series 100 reinforced beams 1:25 scale (40x60x1200 mm) were made and subjected to four-point flexural tests, according to EN-408 (2011) . The results obtained from this testing showed the improvements produced by different reinforcements (Basterra et al 2012). A partial conclusion from this first phase was that the best mechanical / price improvement ratio was achieved with fiberglass reinforcements.
These initial tests also served to highlight the stability problems generated by the reinforcements in fabrics introduced in the glue line. It was necesary to use rigid reinforcements to maintain the fibers in their correct position.

2.3. Fabrication and testing of GFRP rigid bands

GFRP rigid bands of E-glass unidirectional glass fiber with 1200 g / m2 and 2400 g / m2 basis weights were fabricated using vacuum infusion techniques embedded in unsaturated isophthalic polyester resin. Several witnesses of specimens were obtained from these rigid bands by numerically controlled high-pressure water jet cutting and were tested at tensile strength (figure 3), according to ISO 527-5 (2010) 20 units of each grammage, to obtain their modulus of elasticity and ultimate stress of rupture (Table 4). The tests were performed on an INSTRON Model MEN-102/100 tensile testing machine with a 1000 kN load cell, and jaws coined with neumatic closure. The deformation of the specimens during the test is measured with an IBERTEST Mod. IB-MFA 2 extensometer with initial distance (Lo) 50 mm and maximum measurement distance (ΔLmax) of 2 mm.

Fig. 3 Tensile test according to ISO 527-5 of the rigid bands GFRP.

Table 4. Dimensions and mechanical properties of GFRP rigid bands.

Composite	Section (mm)	Young Module (GPa)	Last tension (MPa)
GFRP 1200 g/m^2	2.1 x 15	21.6 (4.4*)	455 (6.3*)
GFRP 2400 g/m^2	3.4 x 15	26.8 (8.4*)	570 (7.2*)

* COV%.

Different types of surface finish were also studied to improve the adhesion of the GFRP rigid bands. Surface abrasion with ceramic grit type B-60 with a diameter of micro ceramic spheres between 0.125 - 0.250 mm showed the best results.

2.4. Selection and characterization of adhesives

Preliminary tests with different types of epoxy resin were carried out to verify the bond between these wood species and FRP. A selection of epoxy adhesives (Table 5) of various commercial brands were tested according to UNE-EN 56543 (1988). Eventually, the Sikadur 30 epoxy resin was selected to be the most compatible with the GFRP reinforcements and wood species used. This epoxy resin incorporated in its composition selected fillers which allowed to increase the thicknesses of the glue line without weakening the bond.

Table 5. Epoxi adhesives tested.

Spabond	Sika	Mapei
Spabond 340LV	Sikadur 30	Mapewood Primer 100
	Sikadur 330	Mapewood Gel 120
	Sikadur 31CF	Paste 140

3. Results and Discussion

3.1. Testing of fiberboard duo beams (MDF) (1:25 scale)

In order to reduce the variability due to the heterogeneity of wood, and to accurately study the effects of GFRP reinforcement, previosly to the assay with *populus* and *pinaster* woods,we tested 60 duo beams (19 + 19) x 60 x 1200 mm, made of medium density fiberboard "FINSA MDF FIBRALAC" and different GFRP ratios. The tests were performed according to UNE-EN 408 (2011) up to break in IBERTEST universal test machine model ELIB-100W with a load cell of 100 kN. Elastic stiffness and ultimate were showed until loads up to 1.5 kN with inductive extensometer LVDT mark HBM WA_20 (figure 4). After this loading step, inductive extensometer was removed and the test was continued until failure.

Table 6. MDF duo beams tested.

series	n	Material	Section	Type
1	20	*MDF FIBRALAC*	38x60x1200 mm	Unreinforced
2	20	*MDF FIBRALAC*	38x60x1200 mm	GFRP 300 g/m^2
3	20	*MDF FIBRALAC*	38x60x1200 mm	GFRP 600 g/m^2

Fig. 4 MDF duo beams tested according to UNE EN-408.

Tests showed significate differences between the results obtained in the 3 groups are significant, with improvements in the elastic moduli (MOE) of 26% and 38% in comparison to the unreinforced section (Fig. 5). Glue line failure or internal fiber glide damage were not detected on GFRP rigid sheets.

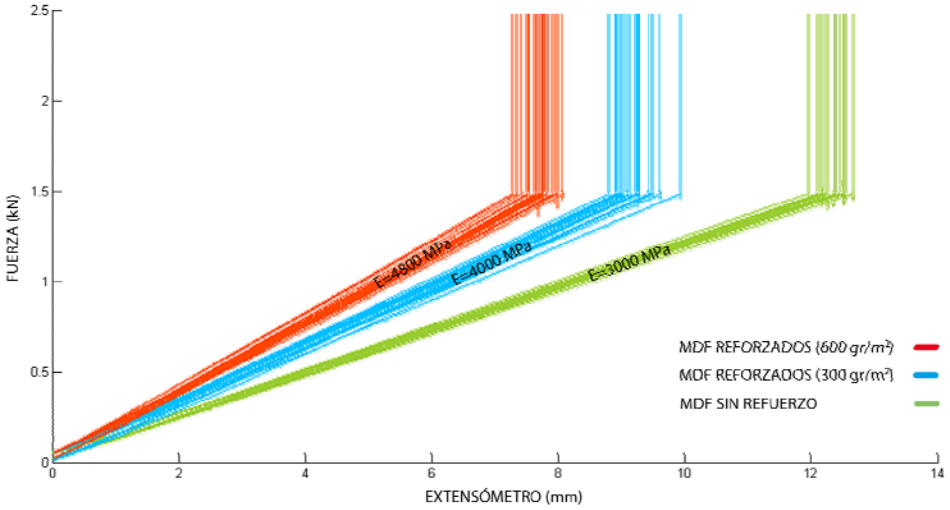

Fig. 5 Force-strain graph of MDF beams according to UNE EN-408.

3.2. Populus x euramericana and P. pinaster duo beams (1: 2 scale)

In view of these partial results obtained 90 poplar and 90 pinaster duo beams reinforced with GFRP rigid bands of different grammages (Table 7) were maden. The fabrication is carried out in a carpenter's workshop under very stable climatic conditions, using Sikadur 30 epoxy resin at controlled temperature (10ºC) and strictly observing working times (<45 minutes) and cured (72 hours). The glueing work of the duo beams is carried out in a maximum time of 48 hours from the machining of the planks. On the rigid bands GFRP a work of superficial improvement is realized by means of blasting with micro spheres ceramic (ø 0.125 -0.250 mm), being realized a previous cleaning to the glue with industrial acetone.

Table 7. Populus and pinaster duo beams tested.

series	n	Material	Section (mm)	Type
4	30	*Populus x euroamericana* I-214	80x140x2500 mm	Unreinforced
5	30	*Populus x euroamericana* I-214	80x140x2500 mm	GFRP 1200 g/m^2
6	30	*Populus x euroamericana* I-214	80x140x2500 mm	GFRP 2400 g/m^2
7	30	*Pinus pinaster* Ait	80x140x2500 mm	Unreinforced
8	30	*Pinus pinaster* Ait	80x140x2500 mm	GFRP 1200 g/m^2
9	30	*Pinus pinaster* Ait	80x140x2500 mm	GFRP 2400 g/m^2

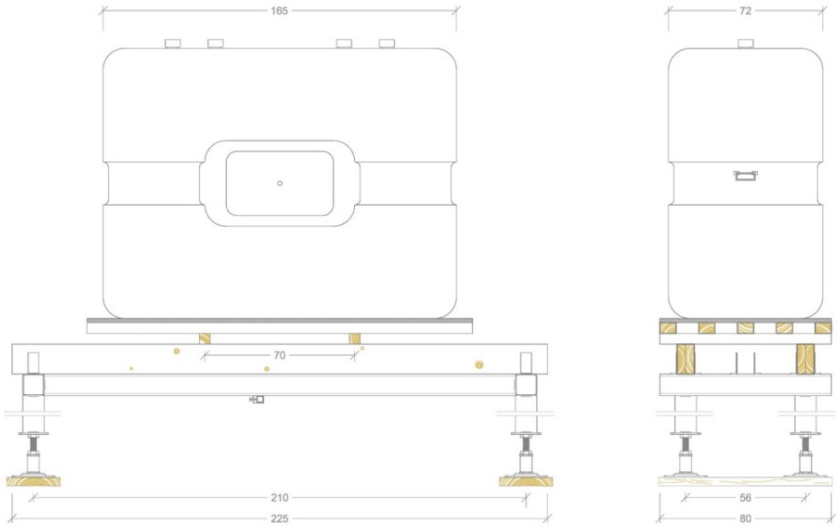

Fig. 8 Creep Test Configuration.

For the deformation monitoring, an HBM data acquisition system, mod. QuamtumX-MX840B, and inductive extensometers (LVDT) HBM, model LVDT WA_100, high accuracy (0.01mm). The model used has a measurement range of up to 100 mm, presenting a great stability (<0.1%) against changes in temperature and humidity. In addition to the previous equipment, another HBM parallel data acquisition system, mod. CanHead CB1010, equipped with HBM strain gauges, model LY41-10 / 120, made of ferritic steel with a 10 mm grid length and a 120Ω resistor, connected to a quarter of a bridge with a compensation band (figure 9).

Fig. 9 Monitoring and loading of creep tests.

The loading of the beams was carried out in several phases or steps of load, in order to register the progressive behavior of the structure, to allow its stabilization, and to verify the correct distribution of loads and deformation on each one of the pieces. In accordance with the guidelines set by UNE-EN 380 (1998) for long-term tests (procedure 3), a loading procedure was developed in magnitude and time shown in figure 10.

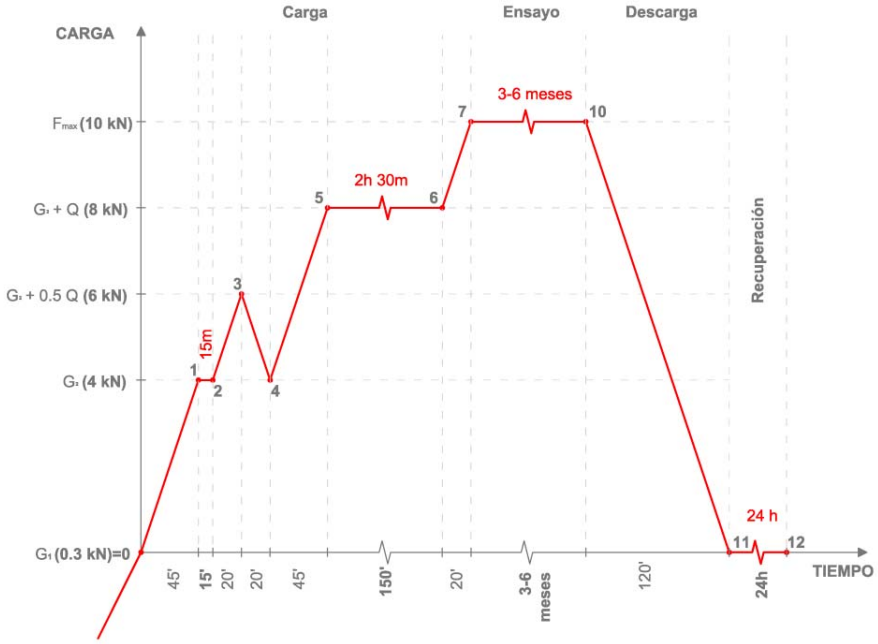

Fig. 10 Loading protocol of creep test according to UNE-EN 380.

In order to know precisely the volume of water introduced into the tank in each loading phase, a Zenner rotary piston counter, model RNK-L-RP-N, with a measurement accuracy of 0.02 liters was used. The velocity of the water flow during filling of the reservoirs was 0.24 l / sec. The deformations of the beams were monitored throughout the trial period (6 months) and, once completely discharged, the monitoring was continued for 24 h in a final recovery phase, in order to know the permanent deformation acquired by the beams, after the discharge. These tests are still active for poplar duo beams.

4. Conclusions

Reinforced fibers

The previous analyzes on different reinforcing materials show that, for the specific case studied, the natural fibers do not present adequate mechanical properties. Among the high modulus synthetic reinforcement fibers (FRP) tested, the best performance / price ratio FRP reinforcements tested in this research are rigid fiberglass reinforcements (GFRPs).

Adhesives

Of all the epoxy adhesives tested, the most compatible adhesive for the GFRP reinforcements and wood species used is the Sikadur-30 epoxy resin.

Reinforced duo beams

Duo control tests, from DMF board, show that the incorporation of GFRP reinforcements in the arrangement employed significantly improves the strength and stiffness properties of the beams, being reached in the case of MDF duo beams improvements of one 26-38% in stiffness with reinforcement amounts from 1.05 to 1.1 of the section.
Reinforced duos beams of Populus with GFRP in amounts of 1.06 to 1.1, their mechanical properties of resistance and stiffness are significantly improved (10-15%), their properties being similar to those of Class C24 resistant lumber with commercially competitive costs.
In addition to directly improving stiffness of the beams, the incorporation of GFRP reinforcements decreases the variability in the mechanical properties of the beams, reducing the incidence of knots and irregularities of the wood, thus increasing the characteristic values of strength and stiffness ..
It is expected that in the reinforced duos beams of Pinaster with GFRP, improvements of stiffness and resistance similar to the ones for the duos beams of Populus will be reached.

Long-term Behavior (Creep)

The data collected so far in the tests of long duration at creep, do not seem to show significant improvements in the rheological behavior of the duo beams due to the incorporation of GFRP reinforcements in the above amounts. However, these statements should be checked at the end of the ongoing trials.

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