Joints in beech-LVL timber frames

Report of a Short Term Scientific Mission

Within the Frame of COST Action FP1004 “Enhance mechanical properties of timber, engineered wood products and timber structures”

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Content

1. Purpose of the Short Term Scientific Mission (STSM)

Glued-in rods have been used for several decades in timber structures to transfer concentrated forces from one member to another. Furthermore they have been applied as a reinforcement of timber members loaded in tension perpendicular to the grain. They are also used in heavy timber constructions where joints with a large load capacity are needed.

Laminated veneer lumber (LVL) is an engineered wood product that uses multiple layers of thin wood assembled with adhesives. It offers several advantages over typical milled lumber: it is stronger, straighter, and more uniform. It is much less likely than conventional lumber to warp, twist, bow, or shrink due to its composite nature. Made in a factory under controlled specifications, LVL products allow users to reduce the onsite labor.

Recently, some experiments were done on beech-LVL. It is a new product with a density of close to 700 kg/m^3 and a characteristic bending strength of more than 70 MPa. It would be very interesting to apply this kind of wood elements in multi-storey residential and commercial buildings and for special applications in structural timber constructions. If we imagine the wooden walls (for example) as frames with infill, a very interesting state of stress and strain occurs in the edges of the frame, where two timber elements are bonded. So, except load capacity, great attention should be given to the behaviour of joints.

The purpose of this mission is to investigate joints in laminated veneer lumber (beech) made by glued-in rods and try to compare results with past researches where same joints were made from hardwood or glulam. Also, state of the art in glued-in rods will be examined and comparison between different design approaches of such systems will be presented.

2. Glued-in rods

2.1. Introduction

Glued-in rods are often considered as “new, innovative and highly efficient” way to connect two timber elements. However, they are used in timber structures since at least 30 years, firstly only for reconstruction of historic or timber structures that are worthy of preservation. During this time, practical use of glued-in rods in timber structures was not always allowed, often because of the unclear legal situation or the lack of efficient and proven design rules. Glued-in rods represent a versatile joint system with advantages of high load transition, appropriate behavior in case of fire, easy application combined with a high level of prefabrication for fast installation. Moreover, what cannot be neglected is the aesthetic appearance of the finished joint.

In 2011 COST Action FP1004 started, aiming to “Enhance mechanical properties of timber, engineered wood products and timber structures”, thereby improving the use of timber or timber products in construction for existing and new applications. One of the main goals of this COST Action is to improve the mechanical performance of connections and reinforcing timber in weak zones. In its first meeting WG1 decided that glued-in rods should become a specific topic with a focus on assessing their performance and a possible common design procedure around Europe. An agreed common design procedure facilitates wider application and acceptance of the connection method. A possible inclusion of the design procedure in Eurocode 5 as a specific output of the COST Action is aimed at. Caused by disagreements, the design rules considering glued-in rods in a pre-version of the EC5 cannot be found in the valid standards. Numerous researchers, designers and technicians with experience in the field of glued-in rods participate in the Action. A common idea is to focus all knowledge and experience and to point key issues on glued-in rods that need to be resolved. This special working group outlines the current knowledge and indicates the design parameters which were studied or weren’t taken into account and requests further studies. Different design methods are in use in a number of countries but contradictions between design models and the studied influence of parameters are conspicuous, so a common European design procedure would be helpful.

2.2. Materials and production

Connections with glued-in rods represent a very large category of hybrid joints since they involve three materials; timber, rod and adhesive (Tlustochowicz et al. 2010). Three materials with distinct different mechanical properties are combined so it represents a very complex system with a specific stress distribution.

Most common material for rod is steel, but lately FRP rods are used often. Mostly rods with metric threads are used, but numerous studies with ribbed bars, smooth bars or V-connections were made. Less common solution is the application with hardwood dowels.

Through the years, huge development in material properties of adhesives was achieved and every year new adhesives with better qualities appear on the market. To summarize, three different adhesive types are often used for bonding rods in timber element: epoxy (EPX), phenol-resorcinol (PRF) and polyurethane (PUR).

Glued-in rods are commonly used for joints with high load bearing capacity so quality of timber element must be guaranteed. Lot of research was done on glulam and softwood, but there are also some researches in hardwood and lately LVL.

Production of such joints must be very precise and strictly controlled by trained personnel so usage of glued connections on the building-site is sometimes difficult and presents major disadvantage for such connections.

2.3. Past research

Connections with different types of glued-in rods have been the subject of many studies since the 1980s and they are becoming popular as they provide good strength and stiffness properties, and efficiency in load transfer (Harvey et al. 2000).

During the past twenty years, despite of many national and international research projects and practical application of glued-in rods in timber structures is quite common there is still no universal standard for design thereof. The reasons for the problems are different approaches of defining the properties of the adhesives and the entire joint respectively. This concerns modeling (strength analysis, linear or non-linear elastic fracture mechanics) and influence of parameters (anchorage length, diameter of the rod, number of rods, spacings, load-to-grain angle, density and moisture content of the timber) and duration of load effects, (load level, creep, mechano-sorptive effects). The complex mechanics of glued-in rods are still unclear as our knowledge about this topic is somehow limited, so there is still lot of questions to be answered. It has to be taken into account, that three materials (steel, adhesive, timber) with distinct different mechanical properties are combined in such joints, so it represents a very complex system with a specific stress distribution. There are many parameters that have influence and affect capacity, load-bearing strength and creep of this system. Three materials with different properties are interacting together which complicates mathematical description for design.

One of the goals of this STSM was to find and gather articles and past researches on this subject and try to obtain which things must be further researched.

There are numerous parameters which have influence on behavior of glued in rods. These parameters can be assigned and placed in some characteristic groups. One of the options was to divide parameters according to material. Numerous articles were gathered, read and put in the table shown on next page. Table contains name of the article and parameters which were varied (or not) in described research. As said before, parameters are placed in 3 groups: timber parameters (timber class, geometry, moisture content, diameter of rod, new or old timber), rod parameters (material, material quality, anchorage length, edge distances, slenderness ratio, one/multiple rods) and adhesive parameters (type of adhesive, glue-line thickness). Table 1. is only small part of big table which will be available for all COST members. Table can help in further researches because it is easy to conclude where is the lack of knowledge and research. For example, it can be concluded from this small part of table that more investigations and laboratory tests must be made on different moisture contents of timber. There are two cells in the table where moisture content of timber is mentioned (highlighted in yellow). In the first cell only *YES* or *NO* can appear, *YES* means that in present study moisture content was varied and *NO* means that in this specific article all specimens had have same moisture content. In second cell is mentioned what percentage of moisture content was examined. So, for first article in the Table, under the section *TIMBER*, in *Moisture content* cell is *NO* and in *Details (%)* cell is number 12, which means that moisture content wasn't varied and MC was 12% for all examined specimens.

List of read articles is in the end of this report.

Table 1. List of read articles with parameters which were varied (or not varied) in every specific article

	Author	Blaß and Laskewitz	Blaß and Laskewitz	Baroth et al.	Gustafsson, Serrano	Steiger,Gehri,Widmann	Bainbridge, Harvey...	Harvey, Ansell..
	Article	Load-carrying capacity of axially loaded rods glued-in perpendicular to grain	Effect of spacing and edge distances on the axial strength of glued-in rods	Glued-in rods connections in bending: experiment and stohastic finite-element modelling	Predicting the pull-out strength of glued-in rods	Glued-in steel rods: A design approach for axially loaded single rods set parallel to the grain	Fatigue performance of GIR in glulam, using 3 adhesive types	Bonded-in pultrusions for moment resisting timber connections
TIMBER	Timber class or species	NO	NO	NO	YES	YES	NO	NO
	Details	C35	C35	GL28h	C24, C35	different densities	C35	LVL Kerto S
	Geometry	YES	NO	NO	NO	YES	YES	YES
	h×b×L [mm]	(240,280,320,400,480,500)×120×10h	120×120×1088	600×136×4900	48×48×40	55×55, 95×95	70×70×576, 120×120×576	L-shaped and in-line bonded rods
	Moisture content	No	NO	NO	NO	NO	NO	NO
	Details [%]	12	12	///	///	///	12	12
	Diameter of hole in timber [mm]	d+1	d+1, d+2	d+4, d+5	d+1	d+2	d+0.5	d+2
	New or old timber	new	new	new	new	new	new	new
ROD	Diameter d	NO	YES	YES	NO	YES	YES	YES
	Details [mm]	16	12, **16**, 20	12, 25	16	M12, M20	8, 16	4, 6, 8, 10, 12
	Material quality and type of rod	NO	NO	NO	NO	NO	YES	YES
	Details	8,8	Steel, 8.8	S500	unknown	8,8	8.8, 10.9	GRP, CFRP
	Anchorage length	YES	YES	NO	NO	YES	NO	YES
	Details [mm]	160, 320	240, **320**, 400	40d	8	105, 140, 175, 220, 275	160	30 - 280
	Edge distances	No	YES	NO	NO	YES	NO	NO
	Details [mm]	3,75d	1.5, 2d, 2.5d, 3d, 3.5d edge, 2d,2.5d,3d, 3.5d rod-rod	2,5d	d	2,29d, 1,38d	3,25d, 3,88d	3,5d
	Slenderness ratio	various	various	40	0.5	7.5 -12.5	10, 20	5 --20
	One/multiple rods	one	multi	multi	one	one	one	one
ADHESIVE	Variation (Type)	NO	YES	NO	YES	NO	YES	YES
	Details	Casco PRF	Casco PRF, PUR, EPX	EPX	PRF, PUR, EPX	EPX	PRF, PUR, EPX	EPX - different kinds of EPX
	Glueline thickness	NO	NO	YES	NO	NO	NO	YES
	Details [mm]	1	0.5, 1	4, 5	1	2	0,5	0,5 --2

2.4. Design methods and proposal

First design proposal was published in 1988 by H. Riberholt, who proposed an equation for the calculation of axially loaded pull-out strength for a single glued-in rod.

$R_{ax,k} = f_{w1} \times \rho_c \times d \times l_g$ lg < 200mm
$R_{ax,k} = f_{ws} \times \rho_c \times d \times l_g^{0,5}$ lg > 200mm

where:

f_{w1}= glue strength factor (for EPX, PRF = 37, for PUR= 46 N/mm^2),
f_{ws}= glue strength factor (for EPX, PRF = 520, for PUR= 650 N/mm^2),
ρ_c = characteristic density [kg/m^3],
l_g = anchorage length [mm],
d = smaller diameter between the rod and the hole [mm].

In the 1990's a lot of experimental work was done and different design methods were presented. Some of the proposals and design rule are shown in Figure 1.

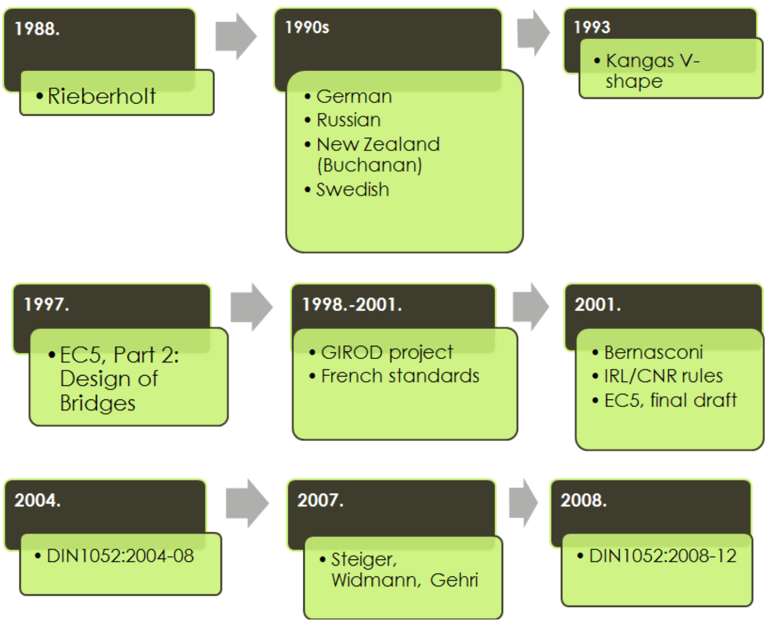

Figure 1. Design methods and proposals in last 20 years

Design methods were included into national design standards and in 1997 a proposal was implemented in a pre-version of the Eurocode 5: Part 2. When, in 1998, the European GIROD project started, the idea was to present a design method for glued-in rods.

The finished project GIROD was divided into several tasks and working groups. It was examined how the moisture content, duration of load, fatigue, effect of distances between the rods and edge distances, properties of the adhesives and some other parameters affects the axial strength of the connection. A lot of laboratory tests were done and guidelines for the manufacturing process and quality control of such joints were proposed. The main objective of this project was to establish design rules and the project result was a new calculation model based on the generalized Volkersen theory (GIROD Project Rapport 2002.). This resulted as a proposal for implementation in a pre-version of the Eurocode 5 as Annex C in Part 2. But at CEN/TC 250/SC 5 meeting in 2003 it was decided to discard the Annex C. Delegates supposed that the scientific research and the proposed text did not show all necessary relationships to realize a design standard.

After the GIROD project there were some other projects and actions such as LICONS and COST Action E13 (Wood adhesion and glued products) dealing with glued-in rods. But a final definition of the mechanics and a universal approach for designing still does not exist. After 2002 a stagnation in research occurred, but in the last 3 years the research has been re-actualized having the purpose to propose a design standard due replacing the several national design standards by Eurocode 5.

A calculation model can take into account several parameters that are linked to different modeling approaches, influences of materials and geometrical parameters, type of loads and durations of load effects and boundary conditions.

This report focuses on the state-of-the-art of glued-in rods, giving a short overview known design models, technical approvals and regulations, national standards and guidance papers. Although there are many proposals for calculation and design of glued-in rods, it is necessary to develop something like technical approval or guidance about safe design of glued-in rods. Also, on the recent CEN meetings, inside TC250/SC5 work program for next five years, glued-in rods are pointed out as an important work item because they are widely used all over the world. Consequently, design rules are desperately needed in Eurocode 5.

Formulas and proposals for pull-out strength of single glued-in rod were analyzed and Excel sheet with numerous design rules was made. Design rules and proposals were placed in table and compared. Screenshot of this document is shown on next picture.

Author	Riberholt, 1998	Buchanan & Townsend, 1990	Eurocode 5 (1997)	Eurocode 5 – 2001	Eurocode 5 – 2003
Formula	$R_{ax,k} = f_{w1} \times \rho_c \times d \times l_g$	$R_{ax,k} = 9{,}2 \times d \times l_g \times (r_d)^2 \times (r_e)^{0,5}$	$R_{ax,k} = \pi \times d_{equ} \times l_a \times f_{v,k}$	$R_{ax,k} = \pi \times d_{equ} \times l_a \times f_{v,\alpha,k}$	$Rax,k = \pi \times d_{equ} \times l_a \times f_{ax,k} \times (\tan\omega)/\omega$
Strength	$R_{ax,k}$ = axial withdrawal strength [N]	$R_{ax,k}$ = axial withdrawal strength [N]	$R_{ax,k}$ = axial withdrawal strength [N]	$R_{ax,k}$ = axial withdrawal strength [N]	$R_{ax,k}$ = axial withdrawal strength [N]
Glue factor	f_{w1}= glue strength factor (for epoxy = 0,037)				$\omega = \frac{0.016\ l_a}{\sqrt{d_{equ}}}$
Glueline thickness					
density	ρ_c = characteristic density [kg/m3]				
anchorage length	l_g = anchorage length [mm]	l_g = anchorage length [mm]	l_a= anchorage length [mm]	l_a= anchorage length [mm]	l_a= anchorage length [mm]
diameter	d = smaller diameter between the rod and the hole	r_d= ratio of hole diameter to rod diameter, r_e=ratio of edge distance (from rod centerline to rod d)	d_{equ} = equivalent diameter = min (d_{hole}, 1.25d) [mm]	d_{equ} = equivalent diameter = min (d_{hole}, 1.25d) [mm]	d_{equ} = equivalent diameter = min (d_h 1.25d) [mm]
timber strength			$f_{v,k} = 1{,}2 \times 10^{-3} \times (d_{equ})^{-0.2} \times \rho_k^{1.5}$ ch.shear strength of the wood around the hole	fv,α,k = c.shear strength of the wood around the hole	fax,k = 5,5 N/mm2
Restrictons and limitations	l_g < 200mm	l_g < 200mm (d=12mm), l_g < 300mm (d=20mm),	l_{min}=max˙(0,4d², 8d)	l_{min}=max˙(0,4d², 8d), la/d < 18	l_{min}=max˙(0,4d², 8d), la/d < 18
Multiply rods			Rax,k = ft,0,k × Aef	Rax,k = ft,0,k × Aef	Rax,k = ft,0,k × Aef
Effect of orientation of the rod			Rax,k = (0,15/sinα) × a0.7 ×(bef)0,7 × (a/h)0,2 × ρk		
DISTANCES	1,5d rod-to-rod, 2d from the edge	1,5d rod-to-rod, 2d from the edge	distances EC5	distances EC5	distances EC5

Figure 2. Comparison between different design rules and proposals

Design rules, methods, proposals and guidance notes for pull-out strength of single rod analyzed in this paper are as follow:

- Riberholt equation, 1998: $\mathbf{R_{ax,k} = f_{w1} \times \rho_c \times d \times l_g}$
- Buchanan & Townsend equation, 1990: $\mathbf{R_{ax,k} = 9{,}2 \times d \times l_g \times (r_d)^2 \times (r_e)^{0{,}5}}$
- Buchanan & Deng for EPX, 1990: $\mathbf{Q_k = 8.16\ k_b\ k_e\ k_m\ (l/d)^{0.86}\ (d/20)^{1.62}\ (h/d)^{0.5}\ (e/d)^{0.5}}$
- Swedish standards, 1992: $\mathbf{F_{t,k}=\pi \times d \times l \times f_{v3}}$
- Russian standards, 1990s: $\mathbf{T=R_{sh} \times \pi \times (d+0{,}005) \times l \times k_1 \times k_2}$
- Eurocode 5, 1997: $\mathbf{R_{ax,k} = \pi \times d_{equ} \times l_a \times f_{v,k}}$
- French rules (according to Riberholt), 1999: $\mathbf{P_{f,k}= 85f_{v,k} \times d \times (l_c)^{0.5}}$
- French rules (for EPX Mastafix), 1999: $\mathbf{P_{f,k}= 104f_{v,k} \times d \times (l_c)^{0.45}}$
- Eurocode 5, 2001: $\mathbf{R_{ax,k} = \pi \times d_{equ} \times l_a \times f_{v,\alpha,k}}$
- Lavisci proposal, 2002: $\mathbf{R_{ax,k} = \pi \times l_g \times (f_{v,k} \times d_{equ} + k \times (d+e) \times e)}$
- Eurocode 5, 2003: $\mathbf{R_{ax,k} = \pi \times d_{equ} \times l_a \times f_{ax,k} \times (\tan\omega)/\omega}$
- GIROD equation, 2003: $\mathbf{P_f = \tau_f \times \pi \times d \times l \times (\tan\omega/\omega)}$
- Steiger, Widmann, Gehri proposal, 2007: $\mathbf{F_{ax,mean}=f_{v,0,mean} \times \pi \times d_h \times l}$
- New Zealand Design Guide, 2007: $\mathbf{Q_k = 6.73\ k_b\ k_e\ k_m\ (l/d)^{0.86}\ (d/20)^{1.62}\ (h/d)^{0.5}\ (e/d)^{0.5}}$
- Rossignon, Espion proposal, 2008: $\mathbf{F_{ax,mean} = \pi \times d_h\ x\ l_a \times f_{v,0,mean}}$
- DIN standards, 2008: $\mathbf{R_{ax,d} = \pi \times d\ x\ l_{ad} \times f_{k1,d}}$

Explanation of equations and symbols can be read from the literature.

What can we conclude from past researches is that pull-out strength depends primarily on interfacial layer and shear strength parameter which is influenced by mechanical and geometrical properties of three different materials. In general an easy calculation model, e.g. as is currently being used in Germany, could be summarized as:

$R_{ax,k} = \pi \times d \times l \times f_{v,k}$ **Equation 1.**

Where:

R = characteristic pull-out strength,
l = anchorage length,
d = diameter,
$f_{v,k}$ = shear strength parameter.

However, the mechanics of glued-in rods are complex, so an accepted simplification of the equation might result in problems like an uneconomic joint design. Figure 3 gives an overview of possible parameters that could influence the pull out strength $f_{v,k}$ if a model like shown above is being used.

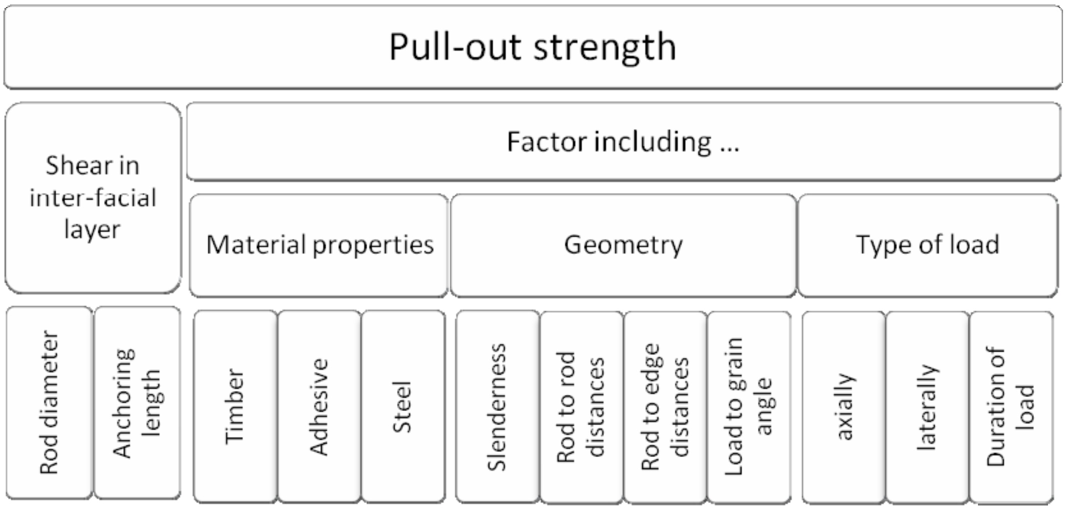

Figure 3. Important parameters that have an influence on the pull out strength.

If we look on the equation 1, there are also numerous questions like which diameter (diameter of rod, diameter of hole, equivalent diameter) and anchorage length (length of bonded rod, equivalent anchorage length) to use and which parameters must be included in shear strength parameter (timber density, MC content of timber, MOE of timber, rod and adhesive, rod surface, rod material, type of adhesive, slenderness ratio, geometrical factors, etc.).

If we take a look on present standards and proposals (Figure 4) it can be easily concluded that existing design proposals differ significantly regarding the final result.

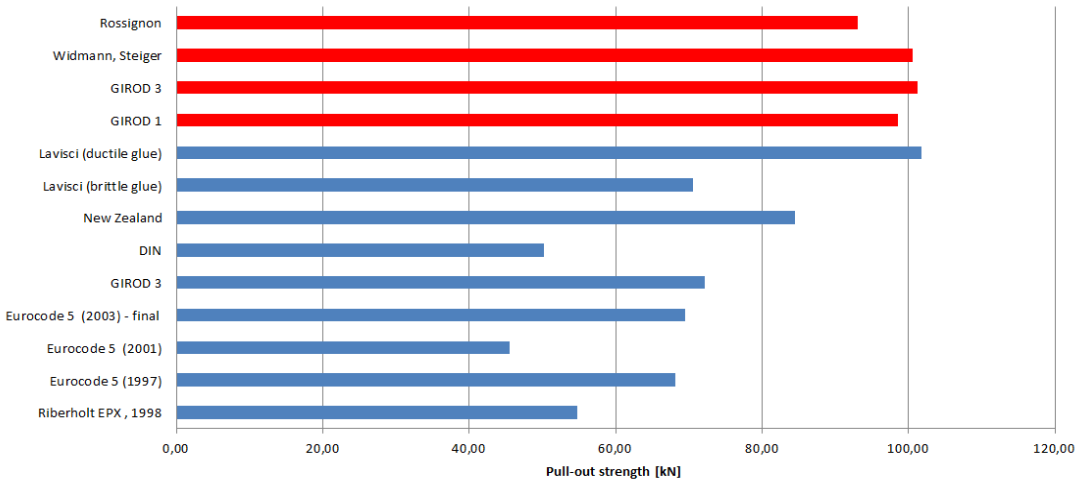

Figure 4. Comparison for pull-out strength [kN] between different design rules (EPX, l=200mm, ρ=370kg/m3, d=20mm, e=2mm). Blue lines are for characteristic values and red ones for mean values.

In Figure 5. characteristic pull-out strength is shown when diameter of rod and density were varied.

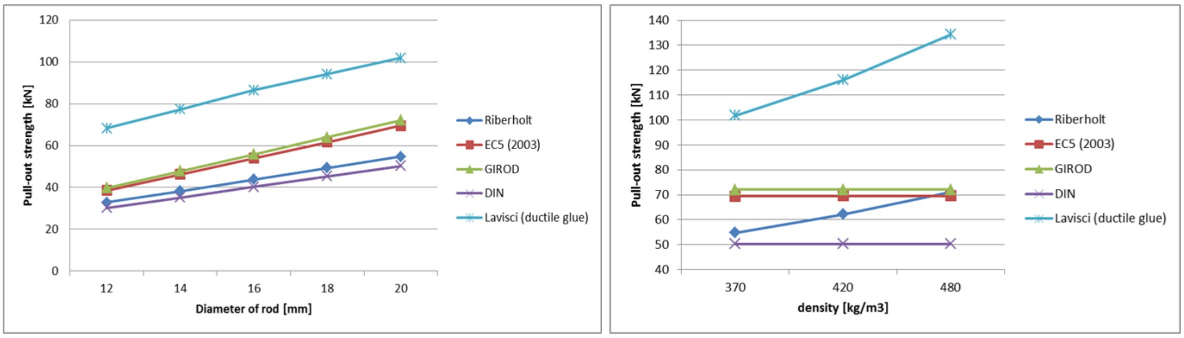

Figure 5. Comparison for pull-out strength [kN] between different design rules when varying diameter of the rod (EPX, l=200mm, ρ=370kg/m3, e=2mm) and density of timber (EPX, l=200mm, e=2mm d=20mm).

Even though several scientific papers on this topic were published recently, a draft version of a proposal for new standard or technical guidance is not mentioned in any of them. In addition to the comparison of design rules, online survey about the usage and requirements for a design rule was made and it is sent to scientists, timber industries and structural designers all over Europe. Copy of this survey is in Annex A.

3. Laboratory tests

3.1. Materials and methods

In this research work four types of LVL made of European beech have been used for research of glued-in rods. Differences between specimens were that veneers were glued at different angles. First LVL specimen is made of veneers with the line with the grain direction, in 2nd specimen veneers were inclined at 30° angle, in 3rd at 45° and in 4th specimen at 90°.

Dimensions of timber varied; length of the specimen was from 260 to 360 mm, height from 110 to 120 mm and thickness was from 95 to 100mm.

Threaded or deformed bars are recommended because of the mechanical interlock conferred in addition to the intrinsic adhesion (Broughton and Hutchinson 2001b). The purpose of the tests was to estimate the carrying capacity of wood or adhesive failure. The rods used were threaded steel bars with metric threads M10, in strength grade 8.8 (characteristic tensile strength f_{ub} of 800 N/mm^2 and characteristic yield strength f_{yb} of 640 N/mm^2) and grade 10.9 (f_{ub} = 1000 N/mm^2; f_{yb} = 900 N/mm^2). Nominal anchorage length was 100 mm.

Two different kinds of adhesive were used in experiments; Epoxy and PUR adhesive. Both can be used and have a technical approval for being used in softwood. Glue-line thickness was the same (1 mm).

The preparation of the test specimens was made as simple as possible. The holes were drilled manually and rods were slightly cleaned and centered inside the hole. The specimen was kept vertical and the glue was pumped through a side hole, so to avoid any pressure on the glue line, as it happens in on-site conditions. The glue in excess was leveled on the upper surface, and the specimens were conditioned fourteen days in [20/65] atmosphere before testing. These were also the average ambient laboratory conditions at the time of testing the specimens. Every sample is identified by a code with a numbers which specify type of LVL and adhesive.

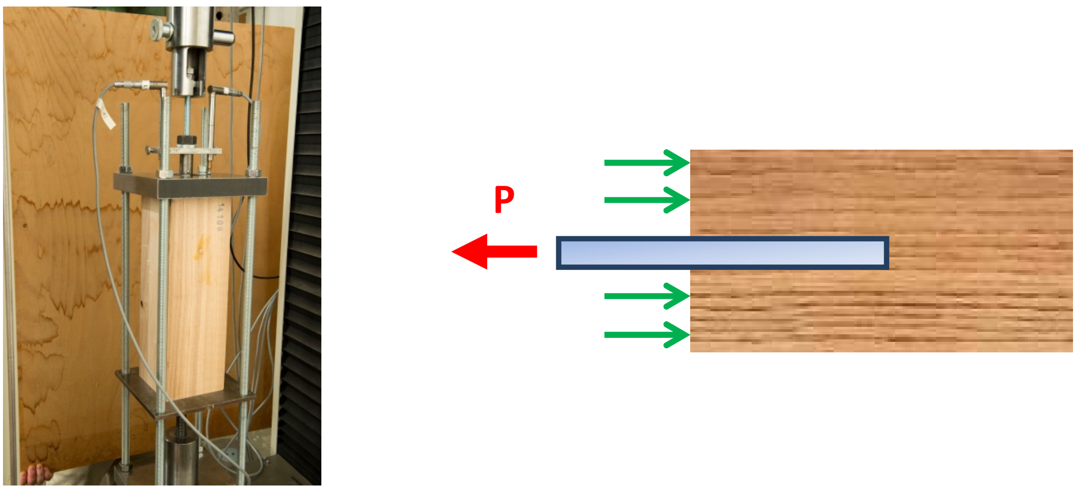

Figure 6. Test setup for pull-out test (pull-compression method)

Pull-compression test on 86 specimens was obtained. Test method was according to the EN 1382 standard. Test setup is visible in Figure 6.

The failure type was visually estimated, with reference to EN ISO 10365:1995. In case of mixed failure type, the specimen was attributed to the one most represented in terms of visible area. Cohesive wood failure includes both ''deep'' wood failure and wood failure at the interface or within the interphase.

3.2. Results

The mode of failure of glued-in rod is strictly dependent on the materials in the connections, their mechanical properties and the properties of the bonds between them. Few failure modes/locations can be distinguished for pulled glued-in rods (Tlustochowicz et al. 2010). These failure modes are:

- rod failure (preferably by yielding),
- failure in shear in the adhesive,
- failure in shear in the timber around the bond,
- failure of the host timber member by splitting or tensile failure.

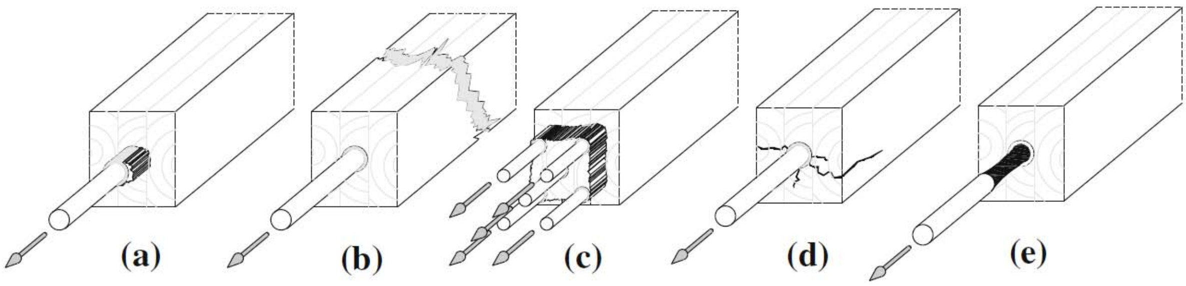

Figure 7. Possible failure modes for timber connections with glued-in rods: a) shear failure along the rod, b) tensile failure, c) shear block failure, d) splitting failure, e) yielding of the rod (Tlustochowicz et al. 2010).

In this research specimens were designed according to the literature to fail due to shear stress exceeding shear strength in the wood along the rod. Although the steel grade of the rods was 8.8 or 10.9, three specimens failed by rod yielding. Failure mode of other specimens was shear failure along the rod; failure occurs in the wood in the vicinity of the adhesive (many fibres are visible on the adhesive after failure) or failure obtained by splitting of timber element. Failure modes from pull-compression tests are shown on Figure 8.

In Figure 9. maximal pull-out force obtained in laboratory tests for specimens in which veneers are in same direction is shown. Comparison between EPX and PUR adhesive is done and it can be concluded that for both adhesives similar results for pull-out strength were obtained.

Figure 8. Failure modes; a) rod failure, b) shear failure along the rod, c) wood splitting (pictures by R. Rosin)

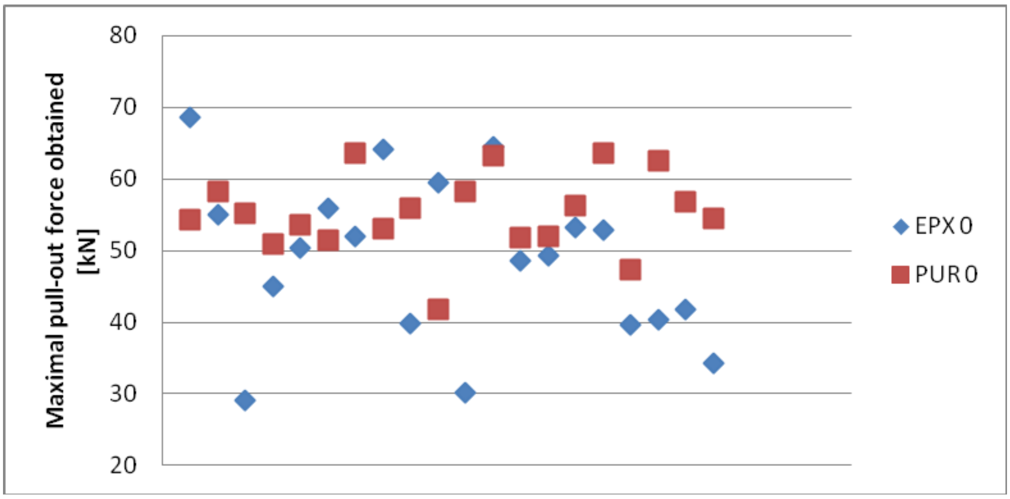

Figure 9. Comparison between PUR and EPX adhesives

In Figure 10. results for four different kinds of LVL are shown. It can be concluded that inclination of veneers doesn't have big influence on pull-out capacity of single glued-in rod.

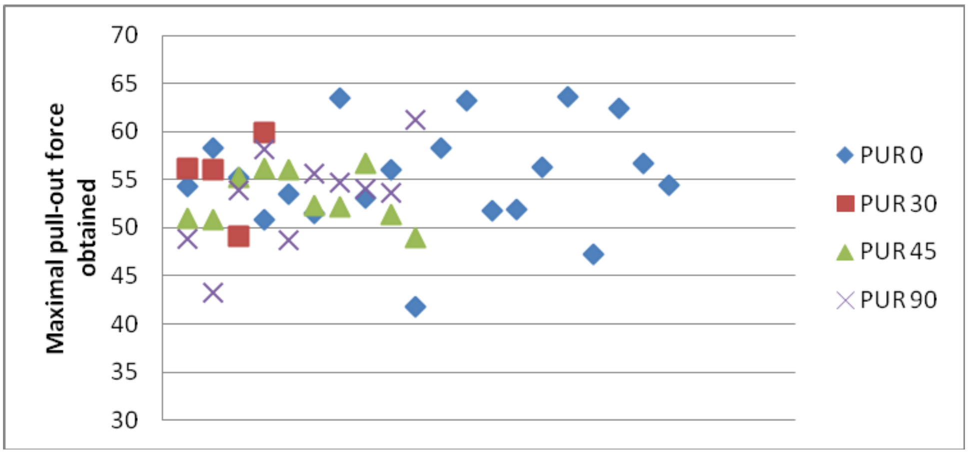

Figure 10. Comparison between different LVL's (PUR adhesive)

In Figure 11. comparison of results from present research of pull-out strength for LVL made with LVL (0°) and from past researches of spruce and ash (J-W van de Kuilen, F Hunger) is done. It can be concluded that density of timber element cannot be neglected in equation for pull-out strength of single glued-in rod.

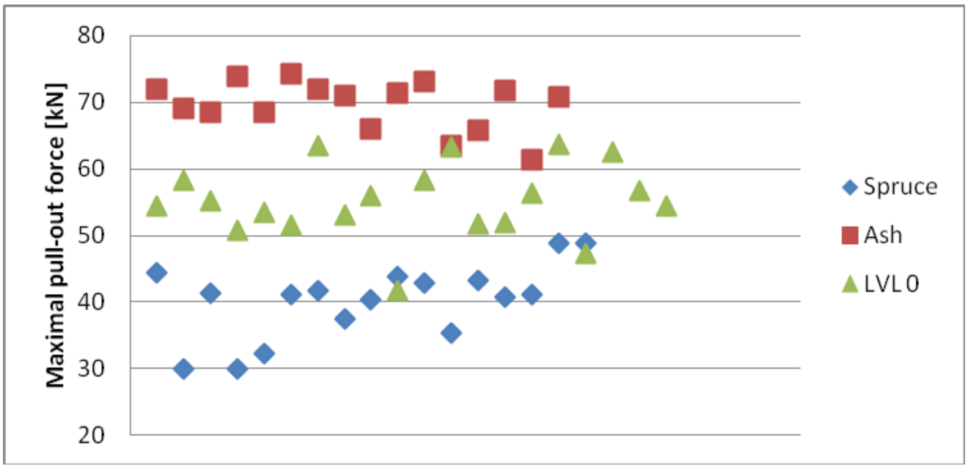

Figure 11. Maximal pull-out force for LVL, ash and spruce

Complete research with detailed conclusions will be accessible to all members of COST Action FP1004.

4. Conclusions

The connections with glued-in rods have gained popularity as they provide solutions both for newly built structures and for strengthening existing ones. The performance of connections with glued-in rods is governed by very complex mechanisms and is dependent on a large number of geometrical, material and configuration parameters and their combinations. During the past twenty years, despite of many national and international research projects and practical application of glued-in rods in timber structures is quite common there is still no universal standard for design thereof. The reasons for the problems are different approaches of defining the properties of the adhesives and the entire joint respectively.

This report was focused on the state-of-the-art in glued-in rods, giving a short overview about known design models, technical approvals and regulations, national standards and guidance papers. Lot of standards is compared and it is concluded that there are unacceptable deviations and differences in final results for pull-out strength of single glued-in rod. Although there are many proposals for calculation and design of glued-in rods, there is no universal design rule and Eurocode 5 is desperately needed.

Huge list of references is prepared for further researchers and table with articles and design rules will hopefully help in recognition of basic problems and identifying information about the lack of research.

Laboratory tests of glued-in rods in LVL made from European beech were made. There was total of 86 specimens subjected to pull-compression test. Conclusion is that there is no significant difference in pull-out strength when using LVL's made from different inclination of veneers. When comparing results for pull-out strength of single glued-in rod in different timber (LVL, spruce, ash), it can be concluded that density of timber element cannot be neglected in equation for pull-out strength of single glued-in rod.

5. Future Cooperation and Research

Future cooperation between Faculty of Civil Engineering Zagreb and Holzforschung München would focus on pull-out strength of single glued-in rod in different wood species and wood products (LVL), and influence of density and load-to-grain angle on capacity of joint.

Some parts of this report will be used for article ***Comparison of existing design rules for glued-in rods and proposal on a procedure for their implementation in European standards*** *(Stepinac M., Hunger F., Tomasi R., Serrano E., Rajcic V., van de Kuilen J.-W.)* which will be presented (if accepted) on CIB-W18 Conference in Vancouver, August 2013.

Also, article about glued-in rods in LVL will be written in cooperation with Prof. Jan-Willem van de Kuilen and Frank Hunger.

ACKNOWLEDGEMENT

The work described in this report was conducted in Holzforschung München (Germany) as a part of COST Action FP1004 ''Enhance mechanical properties of timber, engineered wood products and timber structures''. I would like to acknowledge representatives of COST office for their Short Term Scientific Mission grant, which contribute to successful progress of this research.

In addition, I want to thank to local host Prof. Jan-Willem van de Kuilen that he accepted my request for STSM and give me a chance to do some work In Munich. I want to thank him for his advices, help and guidance of this research throughout the whole STSM. I also want to thank to all colleagues of Holzforschung München for their kind help and support during my stay in München. Special thanks to Frank Hunger who was providing me literature and working with me and helping me in laboratory.

I want to acknowledge COST representatives from BIROD Core group (Serrano E., Broughton J., Widmann R., Harte A., Tomasi R.) for professional help and guidance for future work.

In the end, special thanks to my supervisor Prof. Vlatka Rajčić who was helping me when I was in München. Without her help I could not even go to the STSM.

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Annex A

Online survey can be found on next webpage:
https://docs.google.com/spreadsheet/viewform?formkey=dFBlSnpURldQMXc2NXZiQ2VWdm4yVlE6MQ#gid=0

Author of this report will be very grateful if you can fulfill this survey and spread it to everyone who has interest in glued-in rods.

Copy of online survey can be found on next pages.

Glued-in Rods (GIR) --- Questionnaire

The use of glued-in rods (GIR) is a very efficient technique for connecting timber elements either in reconstruction of old buildings or construction of new ones. However, there are still numerous problems such as lack of design rules and calculation models, test methods, etc. The purpose of this questionnaire is to comprehend the situation about knowledge, use and design of glued-in rods across Europe.

Country * [ ]

From which type of intitution/company are you coming from? *

- ☐ University
- ☐ Timber industry
- ☐ Practice (construction)
- ☐ Practice (design)
- ☐ I'm a student
- ☐ Other: [ ]

Surname and name [ ]

E-mail [ ]

1. Use of glued-in rods in practice

1.1. What is your experience with GIR? *

- ☐ I don't know much about glued-in rods
- ☐ I know something about it (read some articles)
- ☐ I have done some laboratory tests and published one or more articles about it
- ☐ I am using glued-in rods in practice
- ☐ I have published articles and done some work in practice
- ☐ I have a lot of experience in GIR and I have been involved in European projects about GIR (for example: GIROD, LICONS, COST actions)
- ☐ Other: [ ]

1.2. How often do you use GIR in practice? *

	1	2	3	4	5	
Never	☐	☐	☐	☐	☐	Often

1.3. If you don't use it in practice, why?

1.4. If you have some experience with GIR, where have you applied it?

- ☐ Design of new structures
- ☐ Retrofitting of existing structures (historical, modern)
- ☐ Seismic strengthening
- ☐ Other:

1.5. If you have ever designed a structure with GIR, in which buildings have you used it?

- ☐ Timber bridges
- ☐ Long-span buildings
- ☐ Residential buildings
- ☐ New Buildings
- ☐ Historical buildings
- ☐ Other:

1.6. If you have ever designed new structure with GIR, what was the reason for it?

- ☐ Reinforcement of curved beams
- ☐ Reinforcement of notched beams and beams with holes
- ☐ Reinforcement for shear strengthening
- ☐ Reinforcement for tension strengthening perpendicular to grain
- ☐ Reinforcement for compression strengthening perpendicular to grain
- ☐ Engineered connections and elements
- ☐ Column support
- ☐ Reinforcement of joints
- ☐ Hybrid structures
- ☐ Other:

1.7. I have applied GIR for retrofitting of historical buildings in case of:

- ☐ Reinforcement of timber floors
- ☐ Connections between timber structures and masonry

- ☐ Strengthening of critical parts in structures
- ☐ Replacement of decayed parts
- ☐ I have never used GIR for renovation of old buildings
- ☐ Other:

1.8. In which structural members have you used GIR?

- ☐ In columns
- ☐ In beams
- ☐ In trusses
- ☐ In timber plates
- ☐ In joints
- ☐ For anchoring in concrete
- ☐ Other:

1.9. What type of adhesive have you used?

- ☐ PRF (Phenol-Resorcinol-Formaldehyde)
- ☐ EPX (Epoxy)
- ☐ PUR (Polyurethane Reactive)
- ☐ Other:

1.10. What was the usual glueline thickness?

- ☐ Up to 1 mm
- ☐ 1 mm
- ☐ 2 mm
- ☐ 3 mm
- ☐ More then 3 mm
- ☐ Other:

1.11. Which type of rods have you used?

- ☐ Threaded steel bars
- ☐ Smooth steel bars
- ☐ Deformed steel bars
- ☐ FRP bars
- ☐ Wood dowels
- ☐ Other:

1.12. What type of timber has been used in your GIR applications?

- ☐ Glulam
- ☐ Softwood
- ☐ Hardwood
- ☐ LVL (Laminated veneer lumber)
- ☐ CLT (Cross laminated timber)
- ☐ Other wood based products
- ☐ Other: ______

1.13. When do you prefer GIR and when selftapping screws? 1 - I prefer glued-in rods, 5 - I prefer selftapping screws

	1	2	3	4	5
For large diameter of rod	○	○	○	○	○
For more severe serviceability classes	○	○	○	○	○
For in-situ applications	○	○	○	○	○
In case of non-qualified personnel	○	○	○	○	○
Replacement of decayed parts	○	○	○	○	○

1.14. What are the main advantages of GIR in your opinion?

1.15. What are the main disadvantages of GIR in your opinion?

2. Standards / technical guidelines / design rules for GIR

2.1. Are you confident with the present situation for using glued-in rods? *

	1	2	3	4	5	6	7	8	9	10	
I'm not confident	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	I'm really confident

2.2. Are you satisfied about present approvals/standards/regulations? *

	1	2	3	4	5	6	7	8	9	10	
I'm not satisfied at all	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	I'm pretty satisfied

2.3. If you have ever designed bonded connections with GIR, which technical guideline have you used? ____

2.4. Are you aware of any other guidelines for GIR?

- ☐ Yes
- ☐ No

2.5. Which calculation method would you prefer for design of GIR? *

- ☐ DIN Norm 1052
- ☐ EN 1995-2 EC5, Part 2, Annex C - not existing anymore
- ☐ Design Code SIA 265 Timber Structures, Swiss code
- ☐ CNR-DT-206, Italian code
- ☐ New Zealand Timber Design Guide
- ☐ Swedish standards
- ☐ Steiger, Widmann, Gehri proposal
- ☐ GIROD formulas
- ☐ Other: ____

2.6. Which parts of the standard related to GIR should be improved?

- ☐ Pull-out strength
- ☐ Stiffness
- ☐ Edge distances and spacings
- ☐ Multiple rods
- ☐ Definition about materials used (wood species)
- ☐ Definition about materials used (rod materials)
- ☐ Definition about materials used (types of glue)

- ☐ Influence of grain angle
- ☐ Duration of load
- ☐ Production control
- ☐ Other:

2.7. What are the key problems of design rules?

2.8. Would you be interested in European Guidelines for glued-in rods? *

- ○ YES
- ○ NO

2.9. Would you be willing to participate in the creation of European Guidelines about glued-in rods?

- ○ YES
- ○ NO

3. Research

3.1. Which test setup have you applied when conducting pull-out test?

- ☐ Pull-pull
- ☐ Pull-compression
- ☐ Pull-beam
- ☐ Push - push
- ☐ Pull - bending
- ☐ Pull-pile foundation
- ☐ I have never done any laboratory test
- ☐ Other:

3.2. What type of adhesive have you used?

- ☐ PRF (Phenol-Resorcinol-Formaldehyde)
- ☐ EPX (Epoxy)
- ☐ PUR (Polyurethane Reactive)

- ☐ Other: ☐

3.3. What is the usual glueline thickness in structural applications with GIR you have designed?

- ☐ Up to 1 mm
- ☐ 1 mm
- ☐ 2 mm
- ☐ 3 mm
- ☐ More then 3 mm
- ☐ Other: ☐

3.4. Which type of rods have you used?

- ☐ Threaded steel bars
- ☐ Smooth steel bars
- ☐ Deformed steel bars
- ☐ FRP bars
- ☐ Wood bars
- ☐ Other: ☐

3.5. What type of timber has been used in your GIR laboratory tests?

- ☐ Glulam
- ☐ Softwood
- ☐ Hardwood
- ☐ LVL (Laminated veneer lumber)
- ☐ CLT (Cross laminated timber)
- ☐ Other wood based products
- ☐ Other: ☐

3.6. What types of test methodes have you performed?

- ☐ Bending tests
- ☐ Cyclic tests
- ☐ Dynamic tests
- ☐ Tests with multiple rods
- ☐ Lateral tests
- ☐ Fatigue tests
- ☐ Duration of load
- ☐ Load to grain angle

- ☐ Other: ____

3.7. Further laboratory examinations should be focused on:

- ☐ Duration of load
- ☐ Climatic changes - temperature
- ☐ Climatic changes - moisture content
- ☐ Behaviour of joints with multiple rods
- ☐ Influence of grain angle
- ☐ Influence of edge distances and spacings
- ☐ Influence of wood density
- ☐ Other: ____

3.8. Do you participate in current COST Actions?

- ○ Yes, Action FP1004
- ○ Yes, Action FP1101
- ○ Yes, I participate in both COST Actions
- ○ I don't participate