INDUSTRIAL SCALE BEECH WOODLAM GST AND FINGERJOINTS BY MAXIMIZING NATURAL COMPONENTS IN HONEYMOON FAST-SET ADHESIVES

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Abstract:
Fingerjoints and woodlam GST (Glued Laminated Timber) were prepared with beech wood on industrial scale with a cold-set honeymoon type adhesive comprising 65% of natural material, namely condensed flavonoid tannin, already developed to satisfy the relevant adhesives standard requirements. The adhesive system stood up to the scaling up to industrial dimension with good performance of strength. The strength characteristic were compared with those obtained with a 50% natural material honeymoon adhesive already in commercial operation for several decades with yielding even better results. Full scale fingerjoints and woodlam prepared with beech timber gave good results. The fast-set characteristics of the adhesive system were maintained in the scaling up too.

Key words: *woodlam; glulam; fingerjoints; natural adhesives; cold-set adhesives; honeymoon adhesives.*

INTRODUCTION

Nowadays, glued laminated timber (GLT) made of beech wood appears to be of increasing interest for structural purposes due to its high strength and stiffness properties as compared to most softwood species. Beech timber, however, is not even recognized by most standards for structural uses and generally restricted to service class 1 (EN 1995-1-1/A1 2004/2008) and only the furniture, interior joinery, and do-it yourself sectors are still major users of beech timber. The feasibility of using beech timber for structural purposes has been demonstrated by many researchers (Egner and Kolb 1966, Gehri 1985). Within the last ten years the literature shows growing research activities on the structural use of beech timber. These studies include, grading and strength of glued laminated beams made of beech timber (Aicher and Ohnesorge 2011, Frese and Blaß 2005, Aicher and Reinhardt 2007), structural response of finger-joints (Aicher *et al*. 2001, Smardzewski 1996, Karastergiou *et al*. 2006) and glue-line formation and stability within the fingerjoints (Collett 1972, Wake 1976, Sernek *et al*. 1999, Stehr 1999, Stehr *et al*. 1999, Stehr and Johansson 2000).

The adhesives normally used for fingerjointing and to prepare glulam are melamine/urea/formaldehyde (MUF) and phenol/resorcinol/formaldehyde (PRF) resins which require lengthy periods to set and harden to the wanted strength. Separate application fast set "honeymoon" adhesives capable of setting faster than conventional adhesives have been developed to glue large components where presses were inpractical.

Several examples of these "honeymoon" fast set adhesives have been reported. These range from MUF-based systems (Properzi *et al*. 2001) to pure PRF systems (Pizzi *et al*. 1980, Pizzi and Cameron 1984, Properzi *et al*. 2003, Mansouri *et al*. 2009) and to hybrid PRF/tannin systems (Pizzi *et al*. 1980, Pizzi and Cameron 1984, Properzi *et al*. 2003, Mansouri *et al*. 2009). All of these have been now in industrial operation for several years in a number of countries. The most interesting of these systems, from both an economical and technical viewpoint is the system PRF/tannin, 50/50 resin solids by weight. The original system, still in commercial operation, is based on a component A based on the PRF resin with an increased proportion of hardener and a component B based on a water solution of a condensed flavonoid tannin at around 45%-50% concentration and at a high pH 12 or higher. This PRF/tannin honeymoon system has already been studied extensively to improve the proportion of natural, environment friendly material in the adhesive formulation. At the level of laboratory beech strip joints such as in relevant international standards tests (Mansouri *et al*. 2009) this adhesive performed well up to a relative resin solids content proportion by weight of 30 PRF: 70 tannin extract (Mansouri *et al*. 2009). It has however never been tried for full-scale beech fingerjoints and full scale beech glulam.

This article is then focused on the testing of full scale beech glulam beams and beech fingerjoints glued with a honeymoon PRF/tannin adhesive of improved natural material content.

EXPERIMENTAL

A commercial Phenol-Resorcinol-Formaldehyde adhesive was used (Prefere 4535, Dynea, Lyllestrom, Norway). Tannin extract from the bark of black mimosa (*Acacia mearnsii*, formerly *mollissima* de Wildt) supplied by Silva Chimica (St. Michele Mondovi, Italy) was used for the preparation of the adhesive.

The glue mixes were prepared as reported in Table 1. Component A for application to one of the surfaces to be bonded was composed of the liquid PRF resin to which were added the hardener composed in the proportion of 76% paraformaldehyde powder and 24% 200 mesh wood flour. The pH was left at 9. In the experimental glue mixes the resin was substituted by a 50% water solution of mimosa tannin extract in the relative proportions of resin solids content PRF: Tannin of respectively 70:30 by weight (Mansouri *et al*. 2009).

Component B was composed of a 50% mimosa tannin extract solution in water the pH of which was adjusted to 12.4 by addition of a 33% NaOH water solution.

Table 1

Adhesive formulations used for the trials

Tannin: PRF	PRF	Tannin	Hardener	Water	Ethanol	Soda
Component A						
50:50 control	50	-	20	15	3	-
70:30 high viscosity (2400 Pa.s)	35	15	20	18.5	3	-
70:30 medium viscosity (1650 Pa.s)	35	15	20	21.5	3	-
70:30 low viscosity (1050 Pa.s)	35	15	20	25	3	-
Component B						
50:50 control		50	66	-	-	25
70:30 Tannin sol., high viscosity (2400 Pa.s)	-	50	66	-	-	25
70:30 Tannin sol., medium viscosity (1700 Pa.s)	-	50	68	-	-	25
70:30 Tannin sol., low viscosity (1100 Pa.s)	-	50	70	-	-	25

The wood used for the preparation of woodlam GST (Glued Laminate Timber) beams and fingerjoints was beech (*Fagus sylvatica*) wood. The adhesive used must satisfy European Norm 301 (AFNOR 2006a) for adhesives of types I a II in the case of a structure of service class 1 or 2 with the condition that the temperature be always lower than 50°C. The requirements of manufacture are: the wood must have a moisture content comprised between 8% and 18%. It must be bonded less than 24 hours after sanding, thus using fresh wood surfaces. The axial pressure required by the Norm is between 2 and 5N/mm^2 for long planks, that is the case in this study, but no pressure requirements are codified in the EN norm for hardwoods. Thus, the conditions advised by the manufacturer of the fingerjointing and woodlam GST beams industrial lines were used (Weinig-Dimter, Alfed-Hannover, Germany). This indicated a pressure of 13N/mm^2

being required, applied for a minimum of 2 seconds. Thus, to be sure, a pressing time of 5 seconds was used.

The norm NF B 52-010 (AFNOR 2006b) defines as needed for fingerjoint the following parameters: for a fingerjoint to be included in a woodlam GST beam, the characteristic resistance $f_{m,j,k}$ of the joint, determined in four points bending according to the norm NF EN 408 (AFNOR 2010), must satisfy the following limits (equation 1):

$$f_{m,j,k} \geq k_j \times f_{m,gt,k} \qquad (1)$$

$where\ k_j = 1{,}0 + 0{,}07 \times (N-1)$ *for* $N > 1$ *et* $N > 4$

and $k_j = 1{,}2$ *for* $N \geq 4$

The characteristic values $f_{m,j,k}$ for the boards and $f_{m,gt,k}$ for the woodlam are given for a thickness of 150mm (equation 2). For specimens of thickness *h* lower that 150mm it is possible to apply a correction coefficient k_h (equation 3). Such values must be calculated according to the norm NF EN 14358 (AFNOR 2007):

$$f_{m,j,k} = exp\left(\bar{y} - k_s s_y\right) \qquad (2)$$

where:

$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} ln\, f_i$

$s_y = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(ln\, f_i - \bar{y})^2}$ $\qquad$ $If\ s_y < 0{,}05,\ use\ s_y = 0{,}05$

Number of samples n	3	5	10	15	20
Correction factor k_s	3,15	2,46	2,10	1,99	1,93

$$k_h = \left(\frac{150}{h}\right)^{0{,}2} \qquad (3)$$

The exact definition of woodlam GST= Glued Solid Timber) by the CTBA (CTBA 1973) is: woodlam corresponds to thick linear planks of solid wood, fingerjointed or not, of maximum section of 260x300mm. The woodlam beams are composed from 2 to 5 wood planks each of thickness lower than 80mm but greater than 45mm, or of 2 to 3 wood planks for planks of thickness lower than 45mm (Fig. 1).

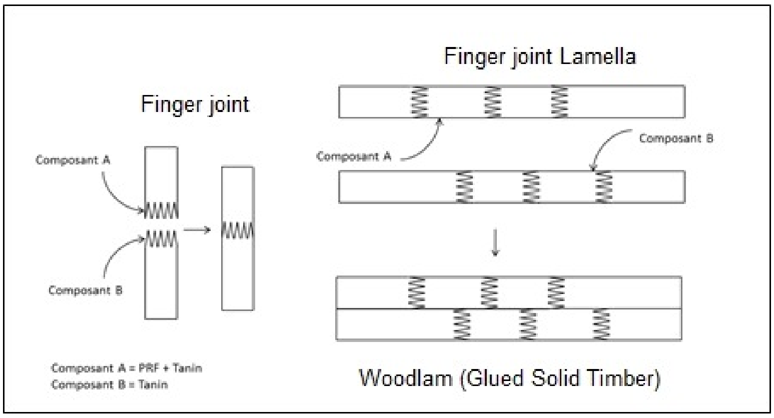

Fig. 1.
Assembly procedure for a woodlam GST beam.

Once again, it is the norm NF B52-010 (AFNOR 2006b) which defines the requirements of the final product. To define the resistance class of the woodlam it is necessary to derive the values allowed by referring to the value of resistance of structural timber of the norm NF EN 338 (AFNOR 2009) by using a transfer coefficient.

$$\text{Strength value allowed} = \frac{\text{Characteristic resistance value}}{2{,}1}$$

While previous work (CTBA 1973) on softwoods have allowed to establish references for softwood woodlam, in the case of the present work based on beech wood the references do not exist and remain to be established, always on the basis of the norm NF B52-010 (AFNOR 2006b). As a consequence beech woodlam of smaller dimensions (60x60x1300mm) has been manufactured on the industrial lines at our disposition using planks of the still acceptable section of 38x68mm under a jointing pressure of $13 N/mm^2$ applied for 5 seconds.

To verify that the adhesive system used was indeed quick setting as reported previously in standardized test (Mansouri *et al*. 2009): 7 pairs of beech boards, in 10 repetitions for each time period of testing and of dimension 550x100x50mm were chosen to yield fingerjointed beech planks of 950x80x42mm, using after adhesive application an open assembly time of 5 minutes and a close assembly time of 10 minutes before applying pressure. After 5 seconds pressing, these were tested at different times of ageing as shown in four points bending according to the norm NF EN 408 (AFNOR 2010) on an Instron 4206 testing machine (High Wycombe, UK) at a rate of 5mm/minute with the aid of an external probe to measure the deflection in the middle of the specimen. Smaller fingerjointed specimens were also prepared and tested. Their dimensions were 380x34.3x16.3mm at a rate of testing of 3mm/minute.

Woodlam specimens of two different sections were also prepared. The bigger had dimensions 1500x90x90mm and the smaller ones 1300x60x60mm. The bigger specimens were tested on the 5 tons mechanical testing machine of the laboratory in four points bending at a rate of 20mm/minute. The smaller ones were tested on an Instron 4467 in four points bending at a rate of 8mm/minute.

RESULTS AND DISCUSSION

In this article's discussion the adhesive called 70:30 Tannin: PRF refers to the component A of the two separate components, A and B, constituting the "honeymoon" fast set adhesive system (Darque 2014). Thus, considering the glue mixes used for the tests as shown in Table 1, the total proportions by weight for the new system are of 65:35 Tannin: PRF resin solids: resin solids, compared with the commercial system where the proportions are 50:50. The proportions chosen for the new systems had been optimized in previous normalized tests (Mansouri *et al*. 2009).

Table 1 shows that the 70:30 adhesive glue mixes were prepared at different viscosity, especially in consideration that in the case of fingerjointing wood end grain to end grain. The viscosity can be a factor influencing overpenetration of the adhesive into the substrate.

The shear strength of the joints according to the Norm NF EN B52-010 (AFNOR 2006b) was determined on the 70:30 experimental adhesive and the 50:50 control for beech glulam of 1,3 meters length. The results are shown in Fig. 2. The 70:30 adhesive system presents an average shear strength of 10.7MPa, after ageing for one week, against a value of 9.0MPa for the 50:50 control system. It is of interest to follow the increase of the glulam joint strength as a function of time when using the experimental adhesive: this is shown in Fig. 3, and shows that values as high as 8MPa are obtained after 4 to 7 hours, with the full strength of 10.7MPa developing after seven days. Fig. 3 shows also that while the average shear strength after 7 hours is of 8MPa joints of much higher shear strength also occurred with a maximum of 13.1MPa. Equally from Fig. 2 it can be noticed that already after three hours clamping the rate of strength increase is already extremely high indicating that the beams can be clamped for only 3 to 4 hours before releasing the pressure and allowing them to further increase the strength out of the press.

ONLINE ISSN 2069-7430
ISSN-L 1841-4737
PRO LIGNO
www.proligno.ro
Vol. 10 N° 4 2014
pp. 3-9

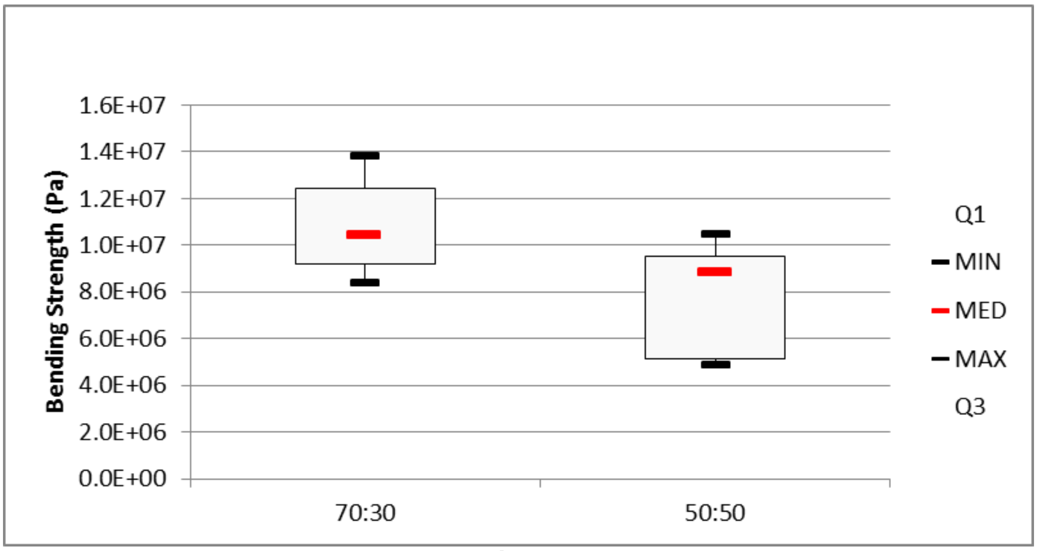

Fig. 2.
Bending strength comparison of fingerjointed beech timber boards of the experimental 70:30 tannin: PRF formulation with the 50:50 formulation. The figure gives the average value and the span of values recorded.

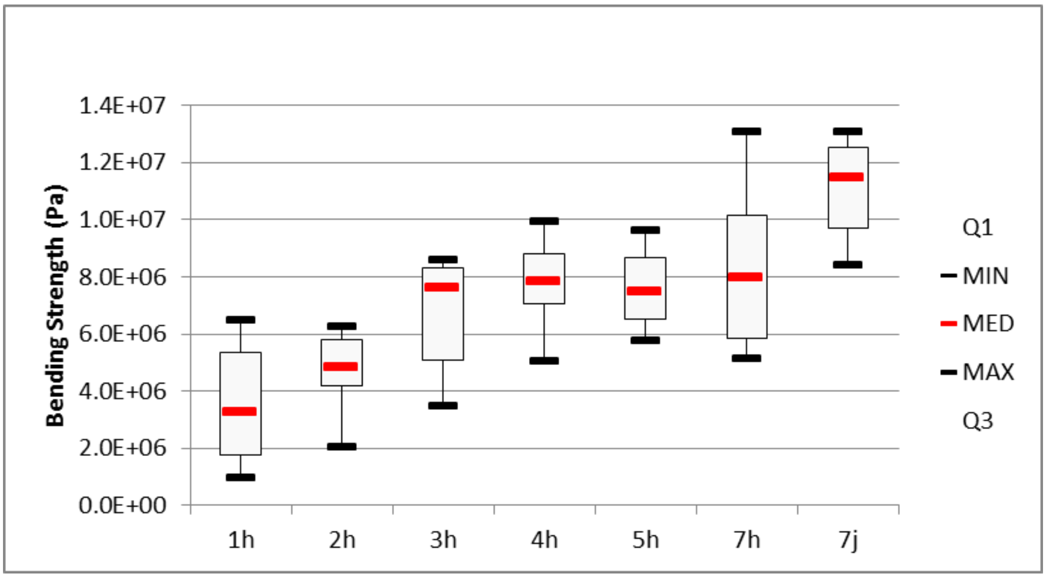

Fig. 3.
Increase in bending strength as a function of time in hours (h) or days (j) of fingerjointed beech timber boards of the experimental 70:30 tannin: PRF formulation. The figure gives the average value and the span of values recorded.

Fig. 4 gives a summary of the bending strength at breakage of the small fingerjointed specimens, the bigger fingerjointed specimens and the engineered solid woodlam beams. It must be pointed out that the strength of these materials has been normalized, namely for specimens of thickness *h* lower that 150mm it is possible to apply a correction coefficient k_h. Such values must be calculated according to the norm NF EN A4358 (see Experimental). This was done in order that the performance of the small and big fingerjointed specimens could be evaluated. From Fig. 3 it can be seen that a moderately lower viscosity of this type of adhesive system gives a better end grain to end grain fingerjoint. The normalized average bending strength of the big size fingerjointed specimens at 42MPa is comparable to that of the small fingerjointed specimens at 43 to 50MPa. However, in the case of the big size fingerjointed specimens the spread of values is greater with some specimens reaching bending strength values of up to 60MPa.

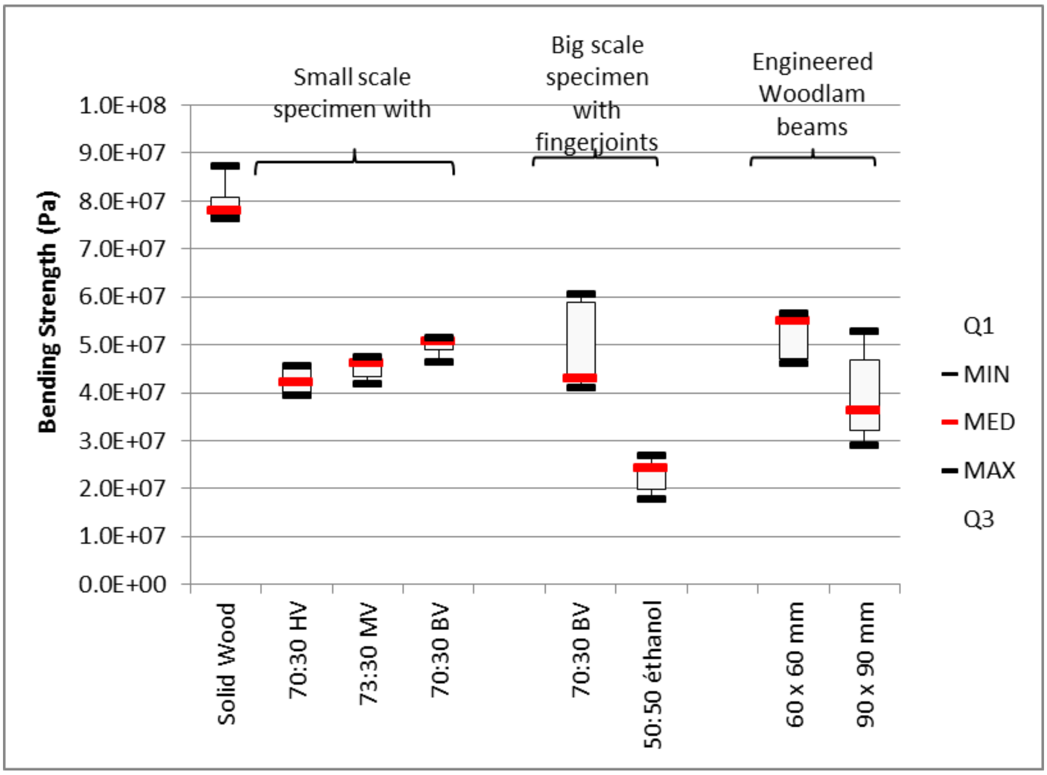

Fig. 4.
Comparison of normalized bending strength of solid beech timber, of smaller and bigger fingerjointed beech timber with experimental 70:30 adhesive at three different viscosities (high = HV; medium = MW; low = BV) and of engineered woodlam GST of sections 60x60mm and 90 by 90mm all bonded with the experimental 70:30 tannin: PRF formulation.

It is important to note that firstly, these results are obtained with an adhesive the natural resin solids content of which is of 65%, cold set and fast setting. Secondly, that these results have been obtained with full scale specimens both fingerjointed as well as of engineered solid woodlam beams. Thirdly, that these results have been obtained with beech wood, a timber species not even recognized by most standards for structural uses. All this was achieved while obtaining results good enough to be comparable to those obtained with timber species accepted for structural application bonded with traditional structural adhesives, only at a faster rate of preparation.

CONCLUSIONS

Fingerjoints and woodlam prepared on industrial scale with a cold-set honeymoon type adhesive comprising 65% of natural material, namely a condensed tannin, already developed to satisfy the relevant adhesives standard requirements, stood up to the scaling up to industrial dimension for fingerjointing and woodlam with good performance of strength while maintaining the fast curing characteristics of this type of adhesives.

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