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International Journal of Current Research
Vol. 5, Issue, 02, pp.079-084, February, 2013

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

Green gluing of two tropical timbers Part II: Mechanical performance of resorcinol-phenol-formol (RPF) and one component polyurethane (1C-PU) adhesives using ayous (*triplochyton scleroxylon*) and frake (*terminalia superba*) substrates

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ARTICLE INFO

Article History:
Received 27th November, 2012
Received in revised form
25th December, 2012
Accepted 24th January, 2013
Published online 14th February, 2013

Key words:
Green gluing,
Resorcinol-phenol-formol adhesive,
One component polyurethane,
Delamination,
Ultimate shear strength,
Tropical wood.

ABSTRACT

Green gluing of ayous (*triplochiton scleroxylon*) and frake (*terminalia superba*) from Cameroon was investigated. Two room temperature curing glues namely resorcinol-phenol-formaldehyde (RPF) and one component polyurethane (1C-PU) were used. Each wood species was conditioned at various moisture contents and their influence on bond linesshear strength assessed. Block shear specimens for RPF were tested dry (in tropical conditions). Wood glued with 1C-PU was tested dry, cold soaked and vacuum- pressure treated. Delamination rates were measured.Results showed a high wood failure rate and a good ultimate shear strength with RPF when the wood moisture content (MC) is below the saturation point (13- 25% MC). The shear strength of both samples decreased with increasing moisture content. A trend of good compatibility of the two woods (single and mixed) is observed with 1C-PU for high moisture content. Slightly delamination of 2.4% was observed (minimum requirement 10%) and all species specimens developed high shear strength with high wood failure percentage.The 1C-PU appeared to be the most qualified adhesive for tropical green wood.

INTRODUCTION

Classical gluing technologies generally require preliminary seasoning of wood to moisture contents below the fibre saturation point (9-14% moisture content) (Properzi *et al*., 2001; Lipke, 2005).However, in some circumstances,the utilisation of the raw wood material is reduced due to drying defects namely twists, bows, springs and cups.These defects need to be removed by machining before the wood can be successfully jointed (Newman and Maun, 2005). This is particularly the case for many tropical african woods which are massive and heavy.The alternative approach proposed in this work consists in gluing tropical wood with high moisture content (green gluing) and then seasoning it to its usual moisture content during use. Earlier work on joining timber with high moisture content was based on finger jointing or edge joining technologies(Newman and Maun, 2005). Finger jointing and edge joining consist in assembling two elements end-to-end in which splices are machined to develop joining surface contacts and improve gluing forces. This technology is widespread in developed countries such as France, USA, Australia and New Zealand (Verreault, 1999). It presents several advantages such as: reduction of defects and saving energy for drying wood, thus allowing a considerable reduction in operation costs as well as an optimization of the quality of the material (Morlier and Courreau, 2002). Apart from the established polycondensation adhesives: urea-formaldehyde (UF), melamine-urea-formaldehyde (MUF), phenol Formaldehyde (PF), and resorcinol-phenol-formol (RPF) resins, polyurethanes (PUR) are gaining popularity for surface gluing and specially on bonding applications in load bearing timber structures. One problem associated with PUR adhesives is temperature-dependent creep (Properzi *et al*., 2003). However, PUR adhesives exhibit excellent joint strength when tested in standard climate conditions. Several 1C-PUR adhesives have been evaluated individually in numerous test programs and have received approval for exterior grade structural application for glulam and finger-jointing in several European countries. Among such promising adhesives, the one-component polyurethane types (1C-PUR) is easy to handle and appreciated as formaldehyde-free, transparent, with possibility of fast and cold systems, suitable for outdoor and indoor applications.

Chemically, the main characteristic of reactive polyurethanes (hence still containing reactive isocyanate groups to yield cross linking in applications) is that the presence of water in the timber should set off and accelerate the cross linking, hardening reaction. Green gluing of wood is nowadays well developed in the northern countries with promising results on temperate timbers (Dunky *et al*., 2008). Information of green gluing properties suitability on tropical wood species is lacking. The use of tropical wood remains a challenge taking into account the great differences observed in the cellular structure and chemical composition of the two categories of wood concerned. This paper focuses on the gluing aptitude of two tropical timbers: ayous (*triplochiton scléroxylon)* and fraké (*terminalia superba*) with high moisture content (green wood). Our

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aimis to demonstrate the interest of green gluing technology with the help of glue joints mechanical analysis. The glulam technique using RPF and 1C-PU adhesives was adopted. Gluing performance was evaluated using delamination and shear tests.

MATERIALS AND METHODS

Ayous and fraké are mainly characterized by a high harvesting potential in the Congo basin, about $2m^3$/ha (FAO, 2006). In addition, they are not subjected to any extinction risk (IUCN, 2011) and there is no particular difficulty concerning their processing (CIRAD, 2011). These arguments have motivated the choice of these species in this study.

Materials

Lamellae preparation and gluing

Sawed samples of ayous and fraké where bought in the local wood market in Yaoundé where they are generally supplied with high moisture contents. The chosen wood was composed of heartwood without defects and knots.According to CIRAD (2011), the average density at 12% MC is 0.38 for ayous and 0.53 for fraké.

Two types of glues were use in this study:

-Resorcinol-phenol-formaldehyde (RPF) which is composed of cascosinol resin 1711,mixed with 2622 hardener to producea resorcinol-phenol-formaldehyde resin adhesive that is suitable for general gluing at temperature range between 10-35 °C.

- A specific 1C-PU (one component polyurethane) (Daude, 2002) especially formulated to glue substrate with high moisture content, up to 70% MC (Pommier, 2006).

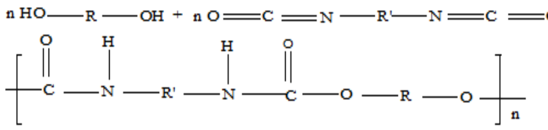
RPF green gluing

Planks were sawn, divided in five batches and conditioned at different moisture contents (MC) in order to evaluate the best moisture condition for the adhesive used. Only straight-grained wood was used. The first batch of planks used as reference was dried in an oven at (105±2) °C to constant mass (anhydrous state) in order to evaluate the moisture of the other batches. Specimens with moisture content above the saturated point of fibre were extracted from freshly sawn unseasoned timbers. Various MC between 12 to 20% were obtained with saturated salt solutions at precise temperature condition in a container (Nkolo *et al*., 2008). The moisture content of the specimens at the time of gluing was evaluated in accordance with the NF B51-004 standard (AFNOR, 1998) and consigned in Table 1. For each MC, one beam was realized. The beam consists of 6 individual lamellae. Every lamella was planned, smoothed and levelled with sand paper in order to obtain a continuous contact between assembled surfaces by removing contaminants such as dust, greasy substances and layers of low cohesion.

The dimensions of a lamella were: 20 mm thick, 100 mm width and 400 mm length. RPF glue was mixed according to the manufacturer's instructions and used within the recommended working life. The adhesive was obtained by mixing the two components (1711 and 2622) and had a pH of 8. An average amount of 200 $g/m^2$was spreaded on each contacting surface of the wood using a plastic spatula. In order to avoid early polymerization before pressing, gluing operations were carried out between 7:00 AM and 8:00AM at a temperature ranging between 25 and 30 °C (~27°C) close to the adhesive storage temperature (20°C). An open assembly time of 20 minutes and a closed assembly time of 35 minutes was use. The minimal polymerization or curing time to obtain acceptable resistances was 6 days. A pressure of 0.2 MPa according to the manufacturer was applied for the two species for 24 hours at room temperature (~28 °C).The glued stock was remove after 24 hours and conditioned for 7 days.

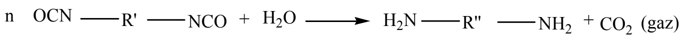
b- 1C-PUgreen gluing

For polyurethane adhesive, only green wood (MC above saturation point of fibber) were used. Polyurethane are well known for their excellent adhesion, flexibility, high cohesive strength low temperature performance, and amenable curing speeds. One-part polyurethanes are based on urethane prepolymers made by reacting and excess of methylene diphenyldiisocyanate with a poyol such that a small amount of isocyanate functional group remains. The remaining functional group react also with OH group of wood without elimination of a small molecule. The basic reactions (Vick and Okkonen, 1998):

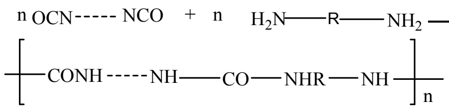


R=aliphatic groups, polyesters, polyether's
R'= aromatic groups

Free isocyanate groups in the adhesive react with moisture on substrate surfaces to complete the cure. Isocyanate reacts with water, with evolution of carbone dioxide.



And then proceeds through an intermediate step to form urea linkages.



Wood specimens were glued in forms of two and six glulam made of single and mixed species. For each species straight grain lamellae, which were free from defects including knots, bird's eye, short grain and any unusual dislocation from the shearing area, were selected. The grain direction was parallel to the longest dimension. Just prior to gluing they were planed and assembled in pairs, (two plies, also called "duos" in this paper) and in beams (six lamellae).The moisture content of the wood during gluing is shown in Table 1.

Table 1. Moisture content (MC) of wood species during gluing

Wood species	Ayous (*triplochytonscleroxylon*)		Fraké (*terminaliasuperba*)	
MC	Average (%)	Standard deviation (%)	Average (%)	Standard deviation (%)
RPF gluing (beams)	13	3	13	3
	20	5	20	5
	25	4	24	4
	54	5	52	5
1C-PU gluing (beams)	48	6	65	16
1C-PU gluing (duos)	48	6	100	9

The spread used for 1C-PU adhesive was $400g/m^2$ for double spreading (one half of the spread was applied to each contacting surface).A rubber rolled mechanical spreader was use. The proper spread was obtained by weighing a piece of wood prior to the application of glue, and then adjusted the right amount of glue on each board. For each press load, glue was applied to two pieces of the two species (for two plies) or to six pieces of each of the two species (for six lamellae beams) to produce one single or mixed glued board.The open assembly and closed time were respectively 2mn and 10 mn. A pressure of 9.6 bars was applied for all the two species for 20 hours. The glued stock was removed after 20 hours and conditioned at 12°C and 65% relative humidity for 20 days. Some squeeze out was observed when pressure was applied in view of the heavy glues spread. This is also true for the RPF glue.

Tests specimen preparation

It was intended in this study to investigate the performance of the adhesive and the species in laminated wood, as measured by resistance to shear by compression loading for all two glues; also resistance to delamination during accelerated exposure to wetting and drying for 1C-PU adhesive.Thus, block shear (EN 392, 1995) and delamination specimens (EN 302-2, 2004) were cut from the small size glulam beams manufactured beforehand.

Block shear test specimen

In each RPF glulam beam,5 specimens (length: 121mm, width: 50 mm, thickness: 40 mm) per humidity content were cut according to EN 392 standard (1995) for shear test. The cut specimens were kept in the following hygrometric conditionsof LMM (Yaoundé) for 28 days: 28 °C, 65% relative humidity.The equilibrium wood MC value was 14 % (tropical condition). Each block shear specimen has 5 glue joints. Thus, 25 glue joints were assessed for a given MC of wood during gluing. In the case of 1C-PU glue joints, two types of block shear specimens were cut from the glued lamellae. A beam has 6 glued lamellae and a "duo" two glued lamellae. The first type is composed of a minimum of 28 "duo shear specimens" (length: 45 mm, width: 45mm, thickness: 40 mm), extracted from the gluing of twolamellae for each species. Each duo has only one glue joint with an area of 45x45 mm². The second type of specimens was composed of two block shear specimens (length : 108 mm, width: 100 mm, thickness: 45 mm) with six lamellae and five glue joints. The equilibrium wood MC was15 %.In the second type, 3 gluing configurations were realized: ayous-ayous, ayous-frake and ayous-frake (frake for external lamellae and ayous for internal lamellae).

Delamination test specimens

In view of the size of the laminated stock, three specimens (length: 108 mm, width: 100 mm, thickness: 76 mm) were cut from each 1C-PU beam, and stabilized at 20°C and 65 % relative humidity for 20 days. According to the EN 302-2 standard, the wood MC in a given specimen must be 12% at the beginning of the test.The specimens did not respect this condition at the end of the 20 days stabilization period because their drying time is important. Thus, three scenarios were considered. In the first one, specimens are dried at 65°C for 22 hours. In the second one, the delamination test starts with the pressure-soak. In the last one, specimens are conditioned at 12°C and 65 percent of relative humidity for three months, in order to reach the equilibrium a wood MC of 12%.

METHODS

Vacuum pressure cyclic test (EN 302-2, 2004)

The test consists in the appreciation of the glued joint resistance after 3 ageing cycles. It indicates the quality and durability of glued laminated timber with respect to the variation ofhygrometric conditions. We remind that three scenarios were defined. Eighteen1C-PU delamination specimens were tested for the two species (2 specimens per scenario for each bonding configuration). For each scenario specimens were placed in a vacuum-pressure tank which was then filled with water at room temperature.All end grain surfaces were exposed to water. A vacuum of (25±5) kPa was drawn and held for 15 mn, after which it was released and a pressure of (600 ± 25) kPa applied for 1 hour. The vacuum pressure cycle was repeated. Specimens were removed from the tank and dried for a period of 17 to 25 hours (22 hours according to theEN 302-2 standard) at 65°C, and 12% percent relative humidity, moving at a velocity of (2,25 ±0,25) m/s. The difference between measured and standard drying time is due to the long term stabilization of tropical wood. The needed time to realize the 3 ageing cycles test is about 5 days. At the end of the last drying cycle in each scenario, the opened length rate of glue joints was measured. The total length of opened glue joints on the two end grain surfaces of each specimen were expressed as a percentage of the entire length of glue lines expose on these surfaces. This value was recorded as percentage delamination of the specimen. The total delamination for the two end grain surfaces of the specimen at the end of the test should not exceed 10 percent of the total length of all glue lines on the two surfaces.

Shear test(EN 392)

A compressive shear stress, parallel to the grain direction, is applied in each bond line. Concerning RPF glue joints, shear tests were realized in the LMM of Yaounde. The block shear test method was used with the standard block shearing tool containing a self aligning seat to ensure uniform distribution of the load. The load was applied by a universal GALDABINI-TERRATEST PMA 50 hydraulic testing machine with a continuous motion (speed rate of 0.03kg/m) untill failure. Shear stress at failure was recorded and wood failure rate was measured onglue joints. Shear tests on 1C-PU glue joints were also performed in laboratory conditions. A ZWICK press was used. Wood failure rates were also measured on block and "duo" specimens. Shear tests were also realized on ayous and frake solid wood in the I2M laboratory, in the aim of a comparison between the performances of these wood species and the related glue joints.

RESULTS AND DISCUSSION

Results

Glue joints delamination

Results for the 1C-PU delamination tests are shown in Table 2. The maximum value of delamination rate is 2.4% (≤10%). Thus,the delamination requirement is respected. The lowest delamination rates are observed in scenario 3. Wood removals can be observed at the end of the drying cycle of delamination. Fig. 1 shows delamination and wood removals on a fraké specimen.

Table 2. Delamination results according to defined scenarios and standards requirements

Glue joints	Specimens	Scenario 1 (%)	Scenario 2 (%)	Scenario 3 (%)	Requirements
Ayous-yous	N°1	0.0	0.0	0.0	≤10% for outdoor use; ≤5% for indoor use
	N°2	1.5	2.4	0.6	
Frake-Frake	N°1	0.0	0.0	0.0	
	N°2	2.1	0.0	0.3	
Frake-ayous	N°1	0.0	0.0	0.0	
	N°2	0.6	0.0	0.3	

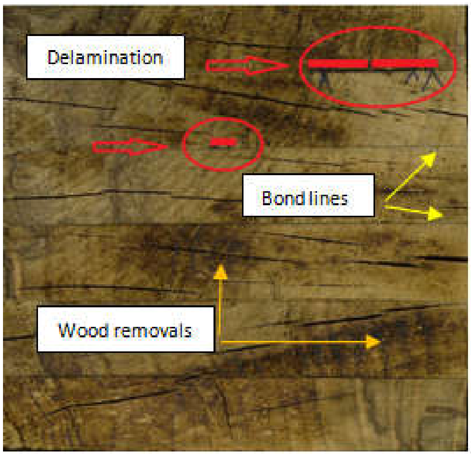


Figure 1: A vue of frake specimen at the end of a drying cycle (specimen n°2, scenario 1)

Shear strength

In the case of structural bonding, the mechanical strength of the glue joint should be at least equal to the mechanical strength of the constitutive solid wood. In addition, the higher the percent wood failure the better is the bond quality, other things being equal.

RPF glue joints

The Average ultimateshear strength of RPF glue joints and woods' failures rate in relation with moisture content of wood during gluingis given in Table 3. The Fig. 2a, 2b and 2c show that the ultimate shear strength of RPF glue joints decreases when wood MCduring gluing increases. Thus, the MC of the woodis a key parameter which affects the mechanical performance of the RPF adhesive joint. This influence is most noticeable when the moisture content of wood increased over the saturation point of fiber. Frake had the highest glue line shear strength with respect to its relatively higher density than ayous.

1C-PU glue joints

In the case of 1C-PU glue joints, we remind that sheartests and wood failure were performed on two types of specimens: "duos" (two lamellae) and block (six lamellae). The average ultimate shear strength and standard deviation of bulk wood and glue joints ("duos"and block specimens) specimens are respectively shown in Tables 4 and 5. Fig. 3 and 4 show thatbondlinesfrom theblock specimens havea betterperformancein shearthan "duos" bondlines andsolid wood.Inthe particular case of"duos" specimens, the mechanical performance offraké-frakéglue joints is bad. This can be explained by the difference ofwood moisture content during gluing (for frake). The average shear strength of mixed block shear specimens (Table 6) stands between low specific gravity wood

Table 3.Average ultimateshear strength of glue joints and woods' failures rate in relation with moisture content of wood (RPF gluing)

Species	Ayous				Frake			
Average wood MC at. 25°Cduring gluing	13	20	25	54	13	20	24	52
Average ultimate shear strength (MPa) at 12% MC	7.08	6.40	5.41	2.73	8.1	5.6	5.4	2.2
Standard deviation (MPa)	0.48	1.27	0.30	0.58	0.66	0.30	0.37	0.40
Wood failurerate (%)	89.0	35.0	0.00	0.00	80.00	40.00	25.70	0.00

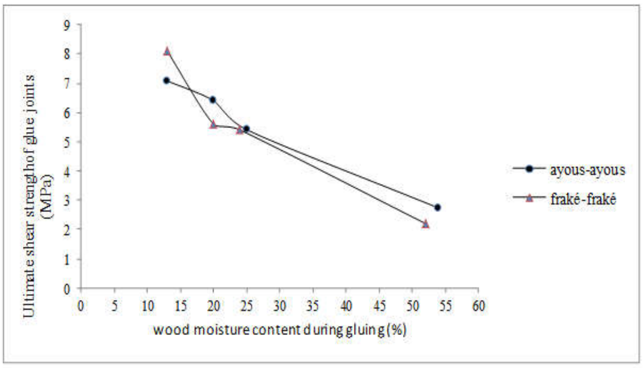


Fig. 2a Influence of wood moisture content on average ultimate shear strength of RPF glue joints

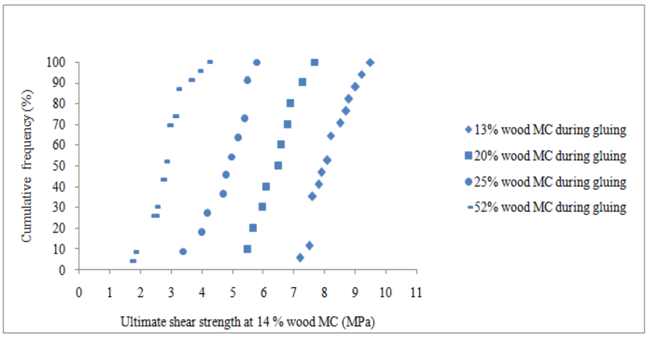


Fig. 2b.RPF frake-frake glue joints: cumulative frequency of ultimate shear strength at various wood MC during gluing

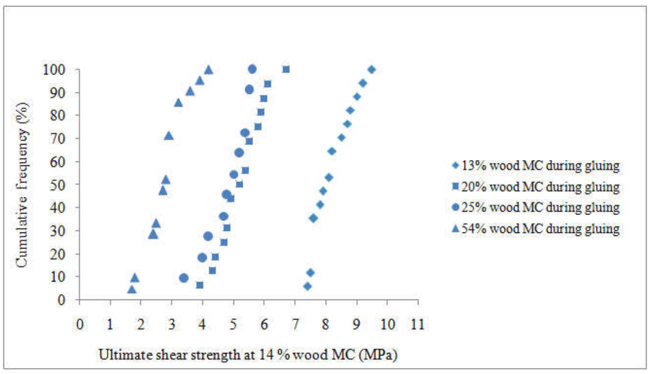


Fig. 2c. RPF ayous-ayous glue joints: cumulative frequency of ultimate shear strength at various wood MC during gluing

Table 4. Averageultimate shear strength and wood failure rates of 1C-PU glue joints ("duos" specimens)

Species	Ayous		Frake	
	Wood	Glue joint	Wood	Glue joint
Moisture content (%)		48	-	> 100
Standard deviation (%)	-	0.6	-	0.9
Shear strength (MPa) at 15% MC	6.5	8.0	8.6	5.3
Standard deviation (MPa)	0.6	0.9	1.1	1.5
Wood failure percent (%)	-	79.3	-	22.3

Table 5.Average ultimate shear strength and wood failure rate of 1C-PU glue joints (block specimens)

Species	Ayous		Frake	
	Wood	Glue joint	Wood	Glue joint
Average MC during gluing (%)		48	-	65
Shear strength (MPa) at 15% MC	6.5	8.7	8.6	9.9
Standard deviation (MPa)	0.6	0.7	1.1	0.6
Wood failure percent (%)	-	78	-	82
Standard deviation (%)		27		14

Table 6: Average ultimate shear strength of single and mixed wood bond lines and glulam shear requirements (1C-PU gluing)

Bond lines	Average Shear Strength (MPa)	Wood failure rate (%)	Average density at 15% moisture content
ayous - ayous	8.75 ± 0.75	78 ± 27	0.36
fraké – fraké	9.86 ± 0.60	82 ± 14	0.45
fraké - ayous	9.22 ± 0.88	86 ± 25	0.40
Glulam requirements (EN 386)	8 9 11	≥ 72 ≥ 63 ≥ 45	-

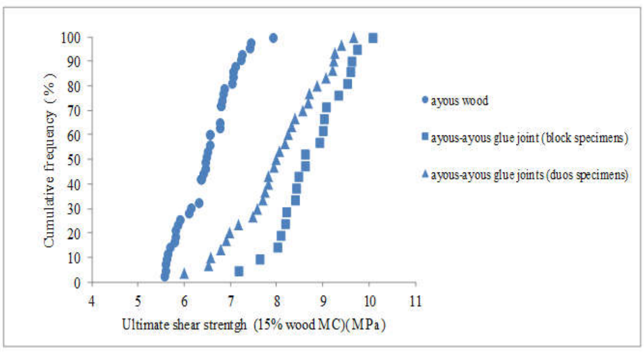


Fig. 3: Cumulative frequency of ultimate shear strength for ayous wood and 1C-PU ayous-ayous glue joints

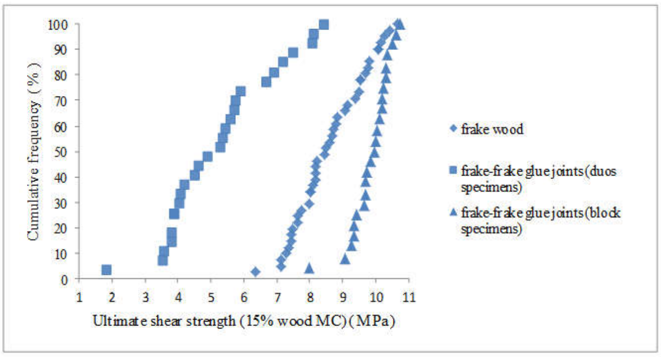


Fig. 4: Cumulative frequency of ultimate shear strength for frake wood and 1C-PU frake-frake glue joints

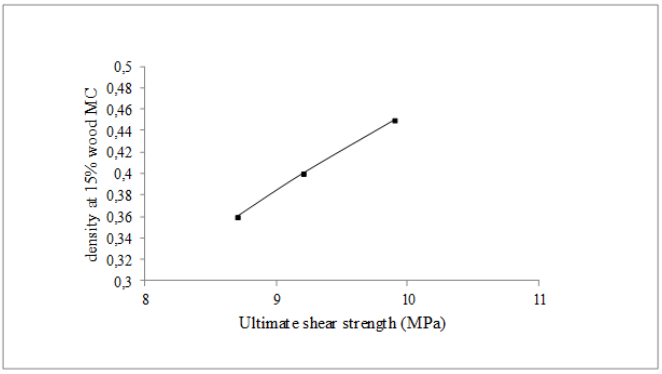


Fig. 5: Influence of wood density on 1C-PU glue joint ultimate shear strength

(ayous) and means specific gravity wood (frake). For this result, one can notice an improvement of mechanical property for relatively lower grade species when mixed with high grade one (Fig.6). 1C-PU adhesive presents the higher performance with respect to wood moisture content during gluing. However when moisture content of wood exceeds 100% 1C-PU adhesive performance decrease dramatically and present poor wood failure percentage.

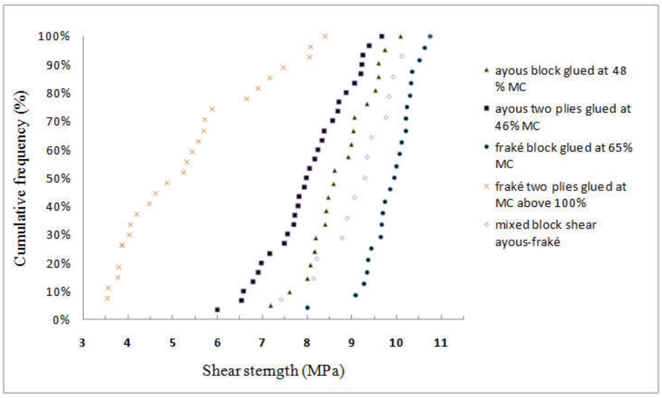


Fig. 6: Cumulative frequency of ultimate shear strength of different wood assembly configurations (1C-PU gluing)

DISCUSSION

With the exception of frake MC (>100%) in the case of "duos specimens" and wood MC above 13% in the case of RPF glue joints, all the gluing parameters were respected according to the manufacturer's recommendations for each type of glue. For each type of glue, thefollowing parameters have been equally used: amount of glue spread, open and close assembly times, press temperature, pressure and clamp period. The differences in their glue bond performances, therefore, arise from the inherent characteristics of the species (specific gravity or moisture content during gluing).

RPF gluing

The general trend observed was that wood moisture at the time of lamellae assembly affects the mechanical performance of the adhesive joint, as we can notice in figures 2a, 2b and 2c. This influence is most noticeable when the moisture content of wood increasesfrom 13% to the fibersaturation point or above for the two wood species. Thus for wood water content ranging between 13 and 17% comparable to air drying, a moderate influence of moisture was noticed for the ayous specimen with wood failure percent of about 80%. This was not the case offraké which was more influenced by wood moisture content even though failure in wood was 90%. The difference in behaviour noted here can be explained by the difference inmeasured specific gravity of ayous (0.36) and fraké (0.45), although both of them are considered as relatively low density wood. These trends are not much different from those obtained by other workers. Khalid (1973) observed that glue line shear strength increases with an increase in specific gravity. Averages of the corresponding shearing strengths are 8.1 and 7.8 MPa for the lowest moisture content (13%), slightly higher than the maximum allowable (386, 2001). Specimens conditioned to a moisture level exceeding fibbers saturation presented, for the fraké as well as for ayous, a 100% rupture in the joint with a very marked influence of moisture noted by the considerable decrease of the breaking strength from 7.08 MPa at 13 % MC to 2.73 MPa at 54 % MC for ayous and from 8.10 MPa at 13 % MC to 2.16 at 52 % MC for frake.

From this result, it is clear that moisture content of wood influences the glue joint (see Figures 2a, 2b and 2c) or the interface. Besides the true interfacial failure that leads to adhesive on one surface and wood on the other, there are a number of other failure zones. The adhesive near the wood may not cure so well leading to failure in the adhesive near the surface. This could be explained by the fact that wood contains excess amounts of water. Thus because RPF is a water-base adhesive, this leads to the deceleration and insufficient or reduction in the rate of polymerization of the resorcinol-phenol-formol adhesive, which adversely affects the cohesion of the adhesive joint. However the results obtained with wood water content close to the saturation point of fibre (20% < MC < 25%) presented a failure both in wood and in the joint (in wood-adhesive interphase). This foresees a possibility of optimization of the moisture contents in assembling wood of the two tropical species with RPF adhesive, whose maximum water content for assembling is 14% (Adhesive Casco AB manual, 2001). In general, the results obtained from test on various wood moisture content can be considered as promising for gluing tropical timbers. Based on knowledge from literature and present results, it can be assumed that optimisation of the process is needed to obtain more results.

1C-PU adhesive

An examination of Table 4 reveals that single plies ("duos") specimens of ayous and frake have wood failure percent, respectively 75. 27 %, 22.70 %.The noted difference probably derives from their moisture content at the time of assembly (48 % for ayous and more than 100% for frake respectively). Block shear specimen of both ayous and frake have high wood failure percent since their moisture content closely equal or slightly lower than two plies specimens. More over the overall picture indicates that for ayous and frake nearly all the failure occurred in the wood rather than in the glue. This indicates that the shear strength of the glue joint is higher than the wood shear strength. These trends were observed in earlier work by Regis Pommier (2006) in the gluing Maritime Pine wood with 70% MC with 1C-PU adhesive. Frake has the high shear strength (9.86 ± 0.60) MPaand a high wood failure rate (82 ±14) % indicating that a good bond was form. Ayous on the other hand, has a low shear strength (8.75 ± 0.75) % value than frake but a high wood failure (78 ±27) % percent, indicating that a good bond was formed and the low shear strength is a result of inherent variability of the wood itself (specific gravity) rather than a poor glue bond.This trend of increasing of the glue shear strength with the increasing specific gravity (Fig.5), have been reported by Goto(1967), Yaggishita and Karasawa (1969). For mixed wood block shear, failure (86 ±25) % occurs in the less dense wood with average shear strength of 9.22± 0.88 MPa. One can notice (as illustrated in Fig.6) an improvement of the mechanical property of less grade wood when mixed with more grade one. Results for delamination test for one component polyurethane adhesive are shown in Table 2. All scenarios have been performed since there is no standard test for green gluing delamination. A general observation can be made that all two species showed less delamination with any of the three scenarios. The maximum delamination of 2.4% was observed with the second scenario for ayous species. There is no distinguishing effect of specific gravity of light density (ayous) and medium density (frake) wood, maybe the expansive force under wetting increase with density. The value of 2.4% obtained is lower than the 10 % maximum requirement for outdoor adhesive according with EN 302-2 (2004) standard. Pre-drying or initial start of the cycle of delamination by the humidification are possible.

However, the standard duration of 22 hours of drying is not sufficient to achieve the targeted humidity of about 15% of all specimens. The performance of adhesive joints can be explained by the probably chemical reactions of free isocyanate functionalities of polyurethane with (OH) hydroxylsgroups of wood by creating high energy covalent bonds. However, there is some doubt about this assumption since others contend that, the presence of large amounts of free water woulddisrupt this reaction (Pizzi 1994). For Frazier (2003) more sophisticated analytical methods will be needed to answer this issue. The small effect of the secondary transition of the polyurethane adhesive used, which is observed at a temperature of 65 ° C, very close to the drying temperature of the specimens can also account for the good stand of the adhesive during delamination test. Tests realized in the I2Mlaboratory show that the glass transition of the glue takes place at -30 ° C. Moreover, there was no influence of extractable components of wood on glued joint. This can be explained by the short time (1 hour) between the beginning of wood machining and gluing operation. One component polyurethane has succeeded to meet the requirements for the delamination test for structural laminating according to EN 302-2 (2004).

Conclusion

This study was conducted on green wood of ayous and frake species. General conclusion can be made from the observations of the behavior of wood samples tested. Green wood of ayous (*triplochyton scleroxylon*) and frake (*terminalia superba*) species showed a poor compatibility with resorcinol-phenol-formol adhesive. However, this glue performs well with the dried two species when containing moisture well below fiber saturation point. Polyurethane adhesive stands as the best opportunity for structural laminating of ayous and frake. Results of test performed showed that ayous and frake have developed high shear strength with high wood failure percent. Low delamination percent was observed for single and mixed specimens of the two wood species which succeeded to meet the requirement for outdoor structural lamination with one component polyurethane adhesive in tropical condition. Density of the species was found to be an important parameter influencing the shear strength test results. Tropical glulam wood product could fulfill the requirements for adhesive bonds according to EN302-2, EN 386 with respect to shear strength, wood failure percentage and delamination. Developed initially for finger jointing short lumber of softwood, green gluing technology appears interesting for tropical species. Green gluing stands as a good opportunity to optimize drying cost and added value to timber industry in developing countries.

Acknowledgment

The authors thank for their financial support the IRD in the frame of a CORUS & AIRES-Sud program.

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