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BONDING PROPERTIES OF TEAKWOOD (*TECTONA GRANDIS* L.f.) WITH PUR AND MUF IN DEPENDENCE ON SURFACE TREATMENT TIME

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ABSTRACT

The present study investigates bonding properties of plantation teak applying polyurethane (PUR) and melamine-urea-formaldehyde (MUF) adhesives. According to literature the bonding properties degrade as a function of the time-span between surface processing and assembling due to extractives that migrate to the surface. In the present study the effect of extractive migration was determined by means of contact angle measurements. In addition the tensile shear strength (EN 302-1) and two different delamination tests were performed. To determine the respective bond strength the samples were assembled in different time intervals after processing, i.e. freshly processed samples as well as three, seven and fourteen days afterwards. Although the contact angle measurements indirectly proofed an increasing amount of extractives on the surface already after the first measurement, both adhesives, PUR and MUF, showed no significant differences in their processing-time-dependent performance. Therefore the assumption of reduced bond strength and higher delamination due to a higher amount of extractives could not be verified in this study. This leads to the conclusion that the material does not have to be assembled within a given time frame after surface treatment with the used PUR and MUF systems.

KEYWORDS: Teak (*Tectona grandis* L.f.), extractives, contact angle, adhesives, bonding strength, wettability.

INTRODUCTION

Teak (*Tectona grandis* L.f.) is a wood species used for numerous specific applications. In the basic characterisation of teak Dahms (1989) mentioned excellent physical and mechanical properties like the high dimensional stability, high strength, high resistance to acids, the high natural durability and high resistance against termites and piddocks. Some of these favourable properties are directly ascribed to the high amount of extractives. On the contrary these compounds can sometimes have negative effects on the wettability of the surface, which leads to reduced adhesion properties (Sanderman et al. 1970, Dunky et al. 2002, Sanderman and Simatupang 1966). Numerous studies about the extractives of teak and their effects on bonding describe an influence on the tensile shear strength of lap-jointed specimens (e.g. Dunky et al. 2002).

In order to prove that there is a verifiable and increasing concentration of extractives on the surface, contact angle measurements can be applied after certain time spans. According to literature it be can assumed that the contact angle will get wider over time which leads to poorer wettability and loss of adhesion (Sanderman et al. 1970).

The main objective of the study is to determine, whether there is a decline of the wettability, a decrease in bonding strength, a change of wood-fracture-ratio and increased delamination in dependence of the time span which elapsed between surface-processing and assembling of the bonded parts. These effects could occur due to extractives migrating to the surface of the specimen.

MATERIAL AND METHODS

The Teak wood samples for all tests originated in plantations situated in Costa Rica. All specimens tested in this study were conditioned to the equilibrium moisture content at the standard atmosphere of 20°C and 65 % relative humidity, which lead to an equilibrium moisture content of 9 %. Before, between and after the processing and each test, the wood was stored under these standardised climatic conditions.
Fig. 1 illustrates the specimen dimensions and experimental setup for the delamination experiments (Fig. 1 A) and tensile shear strength test (Fig. 1B, ÖNORM EN 302-1 2004)

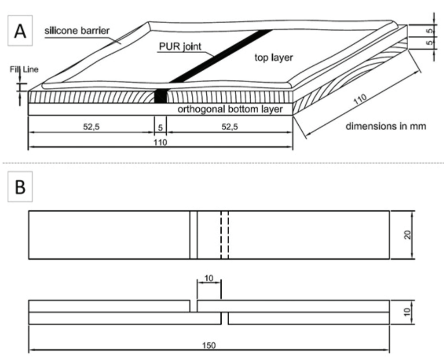

Fig. 1: Experimental setup and specimen dimensions for the delamination test (mm) A); Specimen dimensions used for the tensile shear strength (mm) B).

Contact angle

This measurement was done with a prototype contact angle measurement device from the University of Natural Resources and Live Sciences, Vienna which was built according to the manuals of the product DSA100 from Krüss GmbH (2004-2006). The result of a contact angle measurement depends on numerous factors. As wood is an inhomogeneous material, many wood specific factors must be considered, e.g. temperature, cutting direction, density, moisture content etc. First of all, two samples of teak were prepared which were cut in longitudinal direction from two different lamellas. Both of their surfaces were cut radially. Six positions on each sample were marked in order to allow for repeated measurement in directly neighbouring positions. All measurements were done around those marks but never at an identical spot. This minor shift in measurement positions was done to avoid an influence by the change of moisture content and a potential change in extractives, which might be dissolved and removed by the drop placed on the surface. Both factors influence the results significantly.

The first measurements of the contact angle were performed right after planing and marking the samples. The subsequent measurements were performed after two hours, seven hours, three days, seven days and fourteen days.

To determine the static contact angle, distilled water was used. The measurement was done in laboratory conditions at air temperatures of about 23°C. To determine the contact angle the drop shape analysis programme DSA was used. The programme automatically calculates the contact angle after five seconds using the circle fitting method.

Tensile shear strength

The tensile shear strength was tested according to the standard EN 302-1 (ÖNORM EN 302-1 2004). Today this standard is used to evaluate the performance of wood adhesives. First all lamellas were processed at different times to get a bonding with defined time spans (glued freshly planed; glued three, seven or fourteen days after planing). After preparing the material all lamellas were glued and pressed. Each bonding was made according to the technical datasheets from the glue producing companies. For this analysis two different adhesives were chosen: A two-component melamine-urea-formaldehyde-resin (MUF, Prefere 4535, Dynea Austria GmbH, Krems) with a hardener (Prefere 5046 Dynea Austria GmbH, Krems) and a one-component polyurethane adhesive (PUR, Semparoc 60, Collano Adhesives AG, Sempach, Swiss). For the bonding of the lamellas the adhesives were applied according to the parameters shown in Tab. 1.

Before pressing the MUF coated lamellas together, they were put aside for 15 minutes in order to gain better adhesion with the substrate. After pressing the samples in a laboratory hydraulic press (Langzauner, Austria) they were stored in the climate room for hardening for a minimum of four days.

Then the glued material was cut into samples according to the standard EN 302-1. For each adhesive and each surface processing period eight samples were made. The tensile shear strength was determined in a universal testing machine (Zwick/Roell Z020) according to the above mentioned standard.

Tab. 1: Parameters for the application of the used adhesives.

	MUF Prefere 4535	**PUR Semparoc 60**
Adhesive	two-component	one-component
Mixture ratio of adhesive and hardener	100:30	-
Specific spread	400 g.m^{-2}	200 g.m^{-2}
Application	double-sided with spatula	double-sided with spatula
Curing temperature	70°C	30°C
Applied pressure	1 N.mm^{-2}	1 N.mm^{-2}
Total pressing time	12 min	3 hours

Resistance to delamination

For this analysis special samples with a two-layered construction were prepared as illustrated in Fig. 1. The material consisted of an oiled top layer with a 6 mm PUR-joint in the middle and a bottom layer consisting of solid wood teak lamella which was glued orthogonal to the top layer. The PUR-joint in the middle of the top layer was not object of interest in this case. The test focused on the glue line between top and bottom layer. All glue-lines of the specimens were assembled the same way as the tensile shear strength samples. The only difference was the geometry of the lamellas.

In-service conditions

To determine whether the construction is resistant to delamination, a practical test was conducted. The test set-up was designed like installed parquet with an under-floor heating system. First of all the samples were prepared with a silicone barrier on the edges to be able to treat the surface with a six millimetre deep water film. After the silicone was hardened the samples were put on the bottom plate of the preheated and open laboratory press (Langzauner) with a temperature of 55°C (equivalent to a high temperate under-floor heating system). Immediately afterwards the samples were treated with water, simulating a water-level of 6 mm. After eight hours the water was refilled to 6 mm. In total each sample was treated with approximately 10 mm of water which is the equivalent of 10 litres per square metre. This experiment lasted for 24 hours in total. The surface reached a temperature of 28°C under water and a temperature of 39°C at the end of the test with a dried surface. So the whole set-up simulated a long splash water stress with excessive temperatures of an under-floor heating system.

Extreme conditions

This experiment was done according the standard EN 302-2, a standard for determining the resistance to delamination (ÖNORM EN 302-2 2004).

The samples in this test were the same as before. After the complete impregnation with water in an autoclave the samples were visually examined and the ratio of delamination of the circumference was determined.

RESULTS

All diagrams and statistical tests of the results were carried out with PASW Statistics 18 (former SPSS).

Contact angle

Fig. 2 illustrates the contact angle measurements displayed over time (glued freshly planed, after two hours, after seven hours, after three days, after seven days or after fourteen).

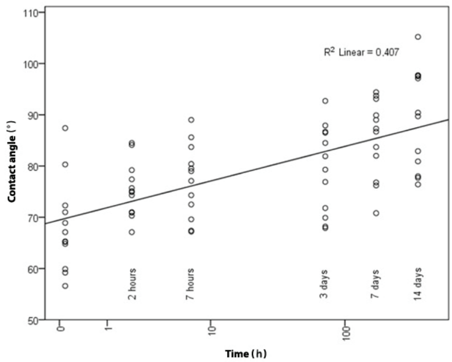

Fig. 2: The contact angle measurements (degree) in different points of time after planing.

Fig. 2 and Tab. 2 illustrate the fact that the contact angle gets wider over time, which means the surface is getting more hydrophobic leading to a lower wettability. Hse and Kuo (1988) also described a change of wettability and curing properties of adhesives with increasing contents of extractives. They came to the conclusion, that extractives can have either positive or negative effects on the wettability and the bond strength of glues. In accordance with this study Yamamoto et al. (1998) examined the hydrophobicity of untreated radially cut teak wood after five seconds and observed average contact angles of 93°. In the present study slightly lower values were reached after 14 days past the surface processing (Tab. 2). This time interval represents the case with the biggest amount of extractives having migrated to the surface.

Tab. 2: Arithmetic averages and standard variances of the contact angle (degree) after different time spans between surface-processing and contact angle measurements.

Points of time	Arithmetic average (°)	Standard variance (°)
0 hours	68.2	8.8
2 hours	75.4	5.3
7 hours	77.1	7.1
3 days	79.5	8.5
7 days	85.3	7.6
14 days	89.3	9.8

This study shows that already after two and seven hours the contact angle is much higher than after planing the surface. After 14 days the contact angle is about 20° higher than directly after processing the surface which means that the surface gets much more hydrophobic over time.

Tensile shear strength

As shown in Fig. 3 the tensile shear strength of all PUR and MUF adhesives are in the range of the shear strength of normal teak wood or above. Wagenführ (1996) determined the upper and lower limit of the shear strength of solid teak wood with 8.3 and 9.5 N.mm^{-2}. In an ideal glue line the adhesive bonding strengths of the glue should show higher performance than the wood itself. In this case the shear strength of wood is tested and not the performance of the adhesive as Konnerth et al. (2006) analysed in their paper.

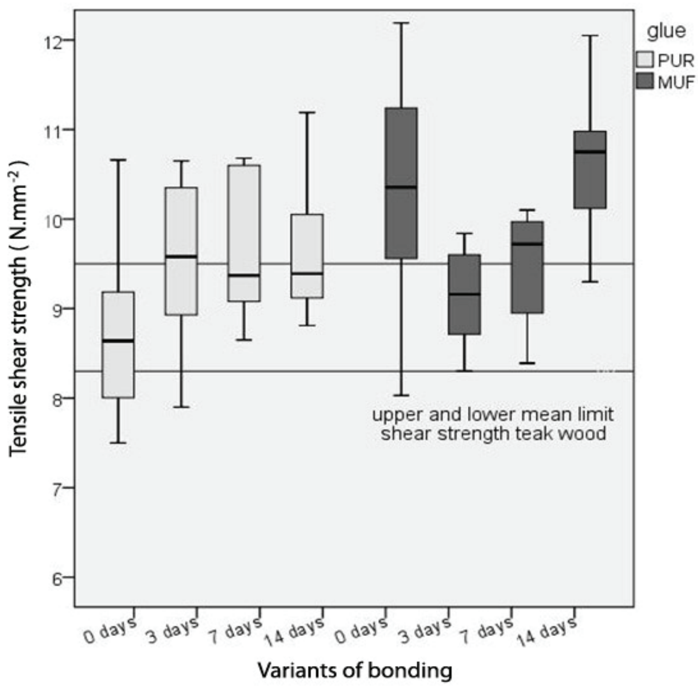

Fig. 3: Tensile shear strength (N.mm^{-2}), processing time, type of adhesive and upper and lower mean limit of shear strength of teak according to Wagenführ (1996).

Tab. 3 and Tab. 4 show the average means of the tensile shear strength (N.mm^{-2}) which were calculated according to Scheffé. The results show homogeneous subgroups which differ from each other by a significance level of 5 %.

It is shown, that the variants of different bonding times do not differentiate, which is one of the major results of this study. As a consequence the bond strength of the used materials is not significantly affected by the time span between surface-processing and gluing.

Tab. 3: Average means of tensile shear strength (N.mm^{-2}) with PUR divided in homogenous subgroups calculated according to Scheffé (variants, which are in one group, do not differentiate among each other).

Categories	N	Subgroup (α = 0.05) 1
PUR, 0 days	8	8.5650
PUR, 3 days	9	9.5378
PUR, 7 days	9	9.5844
PUR, 14 days	9	9.6500
significance		.170

Tab. 4: Average means of tensile shear strength (N.mm^{-2}) with MUF divided in homogenous subgroups calculated according to Scheffé (variants, which are in one group, do not differentiate among each other).

Categories	N	Subgroup (α = 0.05) 1
MUF, 3 days	8	9.1362
MUF, 7 days	6	9.4750
MUF, 0 days	10	10.2760
MUF, 14 days	9	10.5178
significance		.098

Tab. 5 shows the arithmetic averages and the standard variances of the wooden fracture ratio which was estimated for all samples after testing the tensile shear strength.

Tab. 5: Arithmetic average and standard variance of the wooden fracture ratio (%) of different adhesives and different gluing times.

	PUR		MUF	
Points of time	**Arithmetic average (%)**	**Standard variance (%)**	**Arithmetic average (%)**	**Standard variance (%)**
0 days	94	18	100	0
3 days	98	5	100	0
7 days	93	20	97	8
14 days	98	7	100	0

Resistance to delamination

In-service conditions

After testing the samples they were visually inspected for any delamination. No delamination was identifiable in the glue line with this method. Since the test at hands did not result in delamination for any sample, an additional test was performed with extreme conditions to see if delamination can be evoked by exposure to harsher conditions.

Extreme conditions

The result of the delamination test under extreme conditions is shown in Tab. 6. The PUR and MUF samples showed hardly any delamination. Matching the results from the in-service tests, no significant trend to greater delamination over time was measurable. Furthermore the delamination rate of each sample is significantly lower than the maximal acceptable rate of 5 % defined, in the according standard (ÖNORM EN 302-2 2004).

Tab. 6: Arithmetic average and standard variance of delamination in per cent of the circumference of different adhesives and different gluing times.

	PUR		MUF	
Points of time	**Arithmetic average (%)**	**Standard variance (%)**	**Arithmetic average (%)**	**Standard variance (%)**
0 days	0.0	0.0	0.0	0.0
3 days	0.3	0.5	0.0	0.0
7 days	0.0	0.0	0.0	0.0
14 days	0.0	0.0	0.4	0.6

The PUR and MUF adhesives show a very good performance in all tests, which is also a consequence of the high dimensional stability of teak which induces only little tensions in the glue line during swelling and shrinking. This high dimensional stability is already well known for a long time and distinguishes teak from many other wood species as Dahms (1989) or Sanderman and Simatupang (1966) described in their studies.

DISCUSSION

Sanderman et al. (1970) found 40 different chemical compounds in teak wood, all of which influencing the surface properties and the general wood properties of this species. In the case of high ratio of extractives on the surface Dahms (1989) and Wagenführ (1996) described the bonding properties of teak as bad, which could not be confirmed for PUR and MUF resins in this study. The results of the contact angle measurements of this study confirm the hypothesis that the contact angle gets wider over time. This means that the surface becomes more hydrophobic after planing, caused by extractives migrating to the surface. Subsequently it can be assumed, that prolonged periods of time between the gluing and the previous step are in direct correlation to weaker wetting abilities. Dunky and Niemz (2002) respectively Hse and Kuo (1988) suggest, that the extractives can have either positive or negative effects on the glue, the wettability of the assembly parts and the hardening reaction. It depends on the extractives and the type of adhesive if the bonding is affected. However, in this analysis no negative effect could be proven between the bond strengths of PUR and MUF with the used plantation teak. Although the results show an increasing contact angle over time, no negative influence on the tensile shear strength, the wooden fracture ratio and the resistance to delamination could be detected with the applied methods.

CONCLUSIONS

The hypothesis of increasing contact angle over time was verified in this study. However, the expected influence of the rising content of extractives on the bond strength and delamination could not be proven in any analysis for the used PUR and MUF adhesive with the applied testing methods. No significant influence of the time span between the surface processing and the gluing on the bonding strength could be determined. In other words, the teak lamellas do not have to be assembled within a given time frame after the surface processing. For the investigated types of resin the results of this study support a non-time dependent material flow in the production process for companies that are processing teak wood lamellas.

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