Effect of heat treatment on mechanical properties and bonding quality of poplar plywood glued with MUF resins: preliminary results

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PREFACE

ISCHP 2013 is part of the continuing series of conferences previously held in Canada (2007), France (2009) and USA (2011). The main objective of this conference is to bring together the scientific and research communities working on hardwood, from the source to the customer, in order to share knowledge and ideas. International experts, scientists, government employees, hardwood industry representatives, suppliers and customers are invited to discuss recent progress and innovative work in this valuable area. ISCHP promotes the responsible use of the world's leading sustainable, renewable, carbon-absorbing material.

Topics covered by ISCHP 2013:
Hardwood Forestry Practices & Wood Quality
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This year, ISCHP was organized by Cnr-Ivalsa Trees and Timber Institute, Italy. All 37 peer reviewed publications in the proceedings were subject to a rigorous one-sided blind peer review process with a minimum of two reviewers plus an editorial review.

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The organization of an international scientific event like ISCHP requires effort from many individuals and institutions.

Thanks go to the members of the organizing committee who have supported us from the beginning. The Scientific Committee input was critical in assuring the quality of the conference and in securing participation. The Editorial Committee has done a hard work organizing the peer review process and ensuring the scientific quality of the presented papers.

A special thank to the Cnr-Ivalsa as well as to the FCBA, FPInnovation, Virginia Tech and METLA who supported the event.

Thanks also to Associations and Industry sponsors for their support.

Finally I would like to recall the fundamental work of my colleagues P. Burato, C. Capretti, E. Mele, P. Pestelli and L. Scaletti to ensure a good technical support to the conference.

I hope this effort will help to highlight the hardwood and to increase a sustainable management of our forests.

Stefano Berti
Chair Organizing Committee

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Effect of heat treatment on mechanical properties and bonding quality of poplar plywood glued with MUF resins: preliminary results

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ABSTRACT

The present paper covers the preliminary results of an experimental study carried out in order to assess the effects of heat treatment on poplar plywood intended for motorhome application. Tests were performed on poplar (I-214 clone) plywood glued with melamine-urea-formaldehyde (MUF) resin subjected to heat treatment before or after its composition. The treatment was than performed on the single veneers or on the final panels. Veneers and panels were treated at 180-190 °C, respectively, until a dry mass loss of about 5%. Different properties were assessed before and after treatment according to the reference standards: moisture content, density, Modulus of Elasticity (MOE), bending strength and bonding quality. As expected, both moisture content and density at standard environmental conditions decreased after treatment. MOE did not show significant variations, while strength and bonding quality suffered serious reductions. Even if some issues require further investigation, the above experimental analysis showed that heat treatment could be successfully applied to poplar plywood.

1. INTRODUCTION

Heat Treatment (*HT*) is applied to wood in order to decrease its hygroscopic behavior and to improve both its dimensional stability and fungi decay resistance. On the other side, various mechanical properties such as stiffness and strength can be lowered as a result of *HT*. *HT* also causes a darkening of wood.

Significant reviews on the effect of *HT* of wood are available: (Sandberg, Haller, & Navi, 2013), (Navi & Sandberg, 2012), (Finnish ThermoWood Association, 2003), (Kamdem, Pizzi, & Jermannaud, 2002) while literature regarding the effect of *HT* on poplar wood and especially on plywood is limited. Several tests on the mechanical characteristics of *HT* poplar LVL were performed by (Nazerian & Ghalehno 2011) and other studies on the mechanical resistance of silver nanoparticles impregnated poplar were conducted by (Taghiyari 2010).

HT poplar plywood panels were considered by the authors as a possible interesting solution for the motorhome sector. In fact, after *HT* the rough material becomes lighter, with an improved dimensional stability and more durable than conventional poplar plywood. Such products also could be suited for external use where the dimensional stability, durability and water repellent surfaces are essential requirements. The experiments concerned several topics regarding plywood glued before and after *HT* and in particular:

- effects of *HT* on the physical properties of the veneers and of the panels;

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- effects of the *HT* on stiffness (MOE);
- effects of the *HT* on bending strength (MOR);
- effects of the *HT* on bonding quality.

The above experiments were performed on the following materials:

- veneers;
- plywood panels assembled with MUF resins before heat treatment;
- plywood panels assembled with MUF resins after heat treatment of the veneers.

On the whole, the main objective was to determine if *HT* can be considered consistent with the glues currently used for plywood production and if *HT* should be applied on the veneers or could be directly applied on the assembled panels.

2. Material and methods

Legend:
In the present paper the following codes and acronyms have been used:
#: number of samples;
SEC: standard environmental conditions - 20 °C and 65 % RH;
ODS: oven dry state - 103±3 °C;
M_0: untreated oven dry mass [kg];
M_{12}: mass at *SEC;*
ML_0: mass loss due to thermal treatment at *ODS*, referred to *M0* [%];
ML_{12}: mass loss due to thermal treatment at *SEC*, referred to M_{12} [%];
ρ_{12}: untreated density at SEC [kg m^{-3}];
ρL_{12}: density loss due to thermal treatment at *SEC*, referred to ρ*12* [%];
fv: shear strength;
ACWF: apparent cohesive wood failure.

Veneers or panels with dimensions 400x400 mm were heat treated at 180 °C until a 5% of ML_0 (T1). They were first conditioned to standard environmental conditions than measured and weighted. The material used in the tests is reported in *Table 1*.

Table 1: Heat treated poplar base material.

Material	# Layers	Nominal thickness [mm]
Veneer	1	2.1 #15
Plywood with MUF resin	5	9.3 #06

In order to start the treatment exactly from the same stage, samples were oven dried and the mass measured (M_0) as well as the dry mass loss (ML_0) was computed. Both veneers and panels were heat treated. After *HT*, veneers were assembled into panels with MUF resins and tested. The moisture content and the density were determined according to EN 322 and EN 323 standards.

Modulus of elasticity (MOE) and bending strength (MOR) were determined for longitudinal (L) and transversal (T) directions according to the EN 310 standard. The bonding quality was determined according to the EN 314 standard using pre-treatment 5.1.2 (6 hours in boiling water followed by cooling in water at 20 °C for at least 1 hour). As regards the bonding quality, *fv* was determined. As regards *acwf* values, it must be underlined that after *HT* the failure of several specimens did not occur in the shear area of 25x25 mm, but perpendicular to it. In this case, according to EN 314, the test should be considered as non-valid and thus repeated. Owing to this, it was then impossible to determine *acwf.*

The complete set of panels with their dimensions, number of layers and test performed is reported in *Table 2* (panels glued before *HT* present the suffix *_pre*, panels glued after *HT* using treated veneers present the suffix *_post*).

Table 2: Complete scheme of the experiment. The_Test is the control sample, the specie is poplar I-214 clone; the implied glue is MUF. The heat treatment performed (T1) resulted in a 5% of dry mass loss. As regards the EN 314-1 a pre-treatment type 5.1.2 was adopted, and fv (shear strength) was determined. #: is the number of samples involved in the experiment. L or T means longitudinal and transversal samples.

Material	**# Layers**	**Panel thickness [mm]**	**Test EN 310**	**Test EN 314-1**
Plywood panel_Test	5	9.3#06	MOE-MOR (L-T)	5.1.2, fv
Plywood panel_T1_pre	5	9.2#02	MOE-MOR (L-T)	5.1.2, fv
Plywood panel_Test	5	8.8#10	MOE-MOR (L-T)	5.1.2, fv
Plywood panel_T1_post	5	7.6#10	MOE-MOR (L-T)	5.1.2, fv

The significance of the results was analyzed by a non-parametric Kruskal-Wallis statistic test. A non-parametric test was chosen because of the variable number of samples and because of the limited number of samples for some case. A Wilcoxon Rank Sum Test for paired or for independent values was used as post hoc test according to the types of data.

3. Results

3.1. Physical characterization

Density at standard environmental conditions (ρ_{12}), density loss at standard environmental conditions (ρL_{12}) and dry mass loss (ML_0) of veneers and panels glued before treatment (*pre*) are presented in *Table 3*. The results (except ρ_{12}) refer to the same specimens before treatment (paired data). For the panels glued after treatment (*post*), being impossible to make the measurement on the same material, density loss at standard environmental conditions (ρL_{12}) was computed from control samples (independent data). The data of *post* panels are reported in *Table 4*.

Table 3: Rough material subjected to thermal treatment and main physical properties before and after treatment. pre= glued before heat treatment. #: number of samples. SD, where available, in brackets.

Materia l	**ρ_{12} pre treatment [kg m^{-3}]**	**Veneers / panels**	**Treat. temp. [C]**	**Treat. Time [hh]**	**ρL_{12} [%]**	**ML_0 [%]**	**ML_{12} [%]**	**Thickness [mm]**
Material heat treated in the form of veneers								
Veneer_Test	327#05 (8)	V	/	/	/	/	/	/
Veneer_T1	319#05 (14)	V	180	23	NA	5.7	8.3	/
Material heat treated directly in the form of panels								
Plywood panel_Test	454#03 (17)	P	/	/	/	/	/	9.4 (0.1)
Plywood panel_T1_pre	459#04 (18)	P	190	8	7.0	4.9	9.8	9.0 (0.0)

Table 4: Main physical properties of panels composed from thermally treated veneers. post= glued after thermal treatment. #: number of samples. SD, where available, in brackets.

Material	**ρ_{12} post treatment [kg m^{-3}]**	**Veneers / Panels**	**ρL_{12} [%]**	**Thickness [mm]**
Panels resulting after gluing the heat treated veneers				
Plywood panel _Test	490#10 (31)	P	/	8.8 (0.1)
Plywood panel _T1_post	496#10 (22)	P	-1.2	7.6 (0.4)

Concerning panels assembled *post-treatment* using *HT veneers* as shown in *Table 4*, density loss at standard environmental conditions (ρL_{12}) present an opposite behavior if compared to *pre-treatment* panels. In fact Plywood panel_T1 *post* presents an increase of density. This depends on permanent deformation during pressing (a consequence of the reduction of the strength of the material after *HT*). In fact as from *Table 4*, even if after treatment a permanent reduction was expected, the thickness of the plywood panel_T1_*post* resulted to be 7.6 mm against the 8.8 mm of the test, showing that this variation can be ascribed to plastic deformations consequent to panel pressing. This highlights the problem of pressing parameters for treated veneers when assembled into panels after *HT* process.

3.2. *Mechanical characterization*

Both longitudinal (*L*) and transverse (*T*) modulus of elasticity (MOE) and bending strength (MOR) were determined. The test results are summarized in *Table 5*. For every material the values of the treated samples were compared with the control sample by means of a Wilcoxon Rank Sum Test for independent values. The statistical analysis did not show significant differences between MOE both for L and T cases. For MOR a significant difference was highlighted between the control and T1 treatment (*Figure 1*).

Table 5: Mechanical performances of treated and test panels according to EN 310. post= glued after heat treatment, pre= glued before heat treatment.

Material	MOE L [N mm^{-2}]	Group	MOR L [N mm^{-2}]	Group	MOE T [N mm^{-2}]	Group	MOR T [N mm^{-2}]	Group
Plywood panel_Test	5448#30	a	48#30	a	3123#30	a	33#30	a
Plywood panel_T1_pre	4924#18	a	30#18	b	3020#18	a	23#12	b
Plywood panel_Test	6507 #6	a	51 #6	a	2304 #6	a	30 #6	a
Plywood panel_T1_post	6496 #12	a	38 #12	b	2143 #12	a	19 #12	b

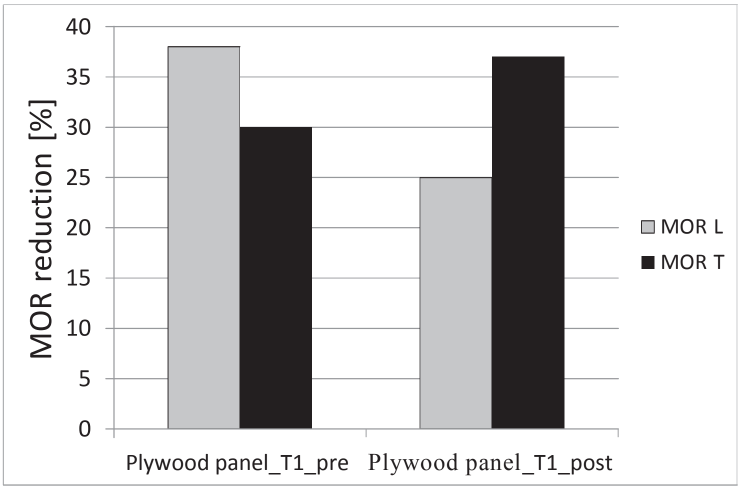

Figure 1: MOR reductions for transverse and longitudinal specimens referred to test samples.

3.3. *Bonding quality*

The main results are summarized in *Table 6*. As can be observed, treated panels present a lower shear strength (*fv)* compared to control panels. These differences were verified by a Wilcoxon Rank Sum Test.

Table 6: Bonding performances of treated and test panels according to EN 314. post= glued after heat treatment, pre= glued before heat treatment. fv: is the shear strength.

Material	Test	fv [N mm^{-1}]	Group
Plywood panel_Test	5.1.2	1.3#45	a
Plywood panel_T1_pre	5.1.2	0.4#45	b
Plywood panel_Test	5.1.2	1.4 #18	a
Plywood panel_T1_post	5.1.2	0.5 #30	b

Figure 2 shows the reduction of *fv* after T1 treatment referred to the control sample. This is likely due to the decreased wood mechanical properties, to the thermal degradation of the glues during *HT* for *pre-treatment* panels, and to the lower adhesion properties of the glues to the heat treated wood for *post-treatment* panels.

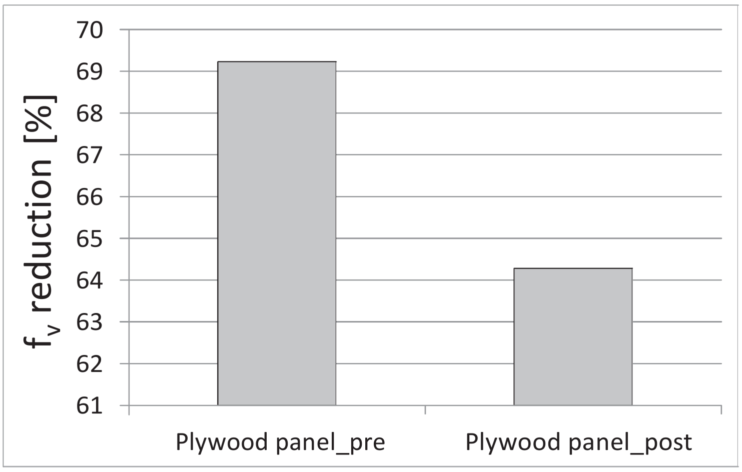

Figure 2: Shear strength reduction after heat treatment according to EN 314.

As already said it was not possible to determine the *acwf* for *HT panels* because of the rupture in a direction perpendicular to the glue line. Therefore further investigations are required in order to understand the effects of *HT* on both glue and wood, this behavior seem to depend mainly on the reduction of strength of *HT* wood.

4. CONCLUSIONS

All panels showed a dry mass reduction after treatment. A reduction was observed for mass and density at standard environmental conditions as well. As regards the mechanical performances of the panels, no statistically significant variations were observed for MOE for either the longitudinal or transverse samples. Statistically significant differences were observed for MOR both for longitudinal and transverse samples. The bonding quality suffered an important reduction of the shear strength after heat treatment with a higher reduction for the panel glued before heat treatment, showing that the effect of the treatment on the glue has a not negligible influence on the final properties of the panel.

5. ACKNOWLEDGMENTS

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References

CEN. (1994a). EN 322: Wood-based panels - Determination of moisture content.

CEN. (1994b). EN 323: Wood bassed panels - Determination of density.

CEN. (1994c). EN 310 - Wood-based panels - Determination of modulus of elasticity in bending and of bending strength.

CEN. (2005). EN 314-1: Plywood - Bonding quality - Part 1: Test methods.

Finnish ThermoWood Association. (2003). ThermoWood Handbook. Changes. Helsinki: Finnish ThermoWood Association. Retrieved from www.thermowood.fi

Kamdem, D. P., Pizzi, a., & Jermannaud, a. (2002). Durability of heat-treated wood. Holz als Roh- und Werkstoff, 60(1), 1–6. doi:10.1007/s00107-001-0261-1

Navi, P., & Sandberg, D. (2012). Thermo-Hydro-Mechanical Processing of Wood (p. 376). EPFL Press.

Nazerian, M., & Ghalehno, M. D. (2011). Physical and Mechanical Properties of Laminated Veneer Lumber Manufactured by Poplar Veneer, 1, 1040–1045.

Paul, W., Ohlmeyer, M., & Leithoff, H. (2006). Thermal modification of OSB-strands by a one-step heat pre-treatment – Influence of temperature on weight loss, hygroscopicity and improved fungal resistance. Holz als Roh- und Werkstoff, 65(1), 57–63. doi:10.1007/s00107-006-0146-4

Poncsák, S., Shi, S. Q., Kocaefe, D., & Miller, G. (2007). Effect of thermal treatment of wood lumbers on their adhesive bond strength and durability. Journal of Adhesion Science and Technology, 21(8), 745–754. doi:10.1163/156856107781362653

Sandberg, D., Haller, P., & Navi, P. (2013). Thermo-hydro and thermo-hydro-mechanical wood processing: An opportunity for future environmentally friendly wood products. Wood Material Science and Engineering, 8(1), 64–88. doi:10.1080/17480272.2012.751935

Sernek, M., Boonstra, M., Pizzi, A., Despres, A., & Gérardin, P. (2007). Bonding performance of heat treated wood with structural adhesives. Holz als Roh- und Werkstoff, 66(3), 173–180. doi:10.1007/s00107-007-0218-0

Taghiyari, H. R. (2010). Study on the effect of nano-silver impregnation on mechanical properties of heat-treated Populus nigra. Wood Science and Technology. doi:10.1007/s00226-010-0343-5