MODERN TECHNOLOGIES FOR BONDING OF HEAT TREATED WOOD

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ABSTRACT:

Heat treatment or thermal modification of wood is often used to improve the dimensional stability of wood and to increase its resistance to decay. Heat treatment also causes some unfavourable effects, such as reduced strength and toughness. Additionally, chemical, physical and structural changes of wood after heat treatment can affect the bonding process with adhesives. Heat-treated wood is less hygroscopic and more hydrophobic. This can alter the wettability of the wood surface with adhesive and the penetration of the adhesive into the porous wood structure. Subsequently, the adhesion and the quality of the adhesive bond are inadequate. The reduced equilibrium moisture content of heat-treated wood can influence the hardening of adhesives. Changes of the pH value of the wood surface might retard or accelerate the curing of adhesives, depending on the type of adhesive used for bonding. This paper presents several studies regarding the bonding of heat-treated wood with different non-structural and structural wood adhesives.

1. INTRODUCTION

1.1. Heat treatment of wood

Heat treatment or thermal modification of wood at elevated temperatures (160 – 260 °C) leads to physical and chemical modifications of hemicelluloses, cellulose and lignin, which can improve the dimensional stability of wood and increases its resistance to decay [1]. However, changes in the chemical, physical and structural properties of wood after heat treatment can affect the ability of adhesives to bond the wood [2]. Thus, heat treatment makes it necessary to adapt the bonding process.

1.2. Chemical composition of wood

Wood cell walls contain three principal polymers: cellulose, hemicellulose, and lignin. A small amount of starch and proteins exist in wood as minor polymeric substances. Besides the cell wall components, there are numerous compounds, which are called the extractive materials of wood. They are low-molecular-weight substances, divided into organic and inorganic matter. The inorganic matter is ash, whereas the organic matter is commonly called extractives. They are not part of the wood substance, but are deposited in cell lumen and cell walls [3].

Extractives contents vary within trees, and are highly concentrated in certain parts of the tree. Extractives can be removed from wood by means of polar and non-polar solvents. Even though extractable components contribute only a few percent to the wood mass, they may greatly affect the physical and mechanical properties and processing of wood (e.g. bonding with adhesives).

1.3. Effect of extractives on wettability and adhesion

Changes of wood wettability have often been attributed to migration of extractives to the surface. After thermal treatment of wood, the extractable compounds are often responsible for poor wettability and weak adhesion [4]. The extractives are common and important sources of surface contamination harmful to wood adhesion. Bonding strength is adversely affected by the degree of wood surface contamination. Deposition of extractives on the surface may reduce adhesive bond strength in many ways. High extractives concentration on the surface increases the possibility of contaminating and reducing the cohesive strength of the adhesive. Extractives may block reaction sites on wood surfaces and prevent adequate wetting by the adhesive. The amount, the type, and the nature of extractives affect wood wettability. Wood extractives are polar and non-polar. Non-polar extractives are primarily responsible for low wettability of a wood surface by water-borne adhesives. Oxidation of extractives tends to increase the acidity, which interferes with adhesive cure [5].

1.4. Chemical interference with adhesive cure or bonding

The alkaline or acidic nature of the wood surface could impede bonding by interfering with the cure of the resin. The curing of adhesives could be retarded, accelerated, or not affected by a changed pH value of the wood surface. The curing problem is more likely associated with species that have a high amount of acid extractives such as tropical hardwood species, pine, and oak. The acidity of oak surfaces significantly reduced the bond strength of resorcinol adhesives and prolonged the curing of phenolic adhesives. On the other hand, a low pH of extractives concentrated on the wood surface accelerates chemical reactions of acid-catalysed urea-formaldehyde adhesives [6].

2. EXPERIMENTAL

Three different experiments were conducted:

- Influence of heat treatment of spruce on bonding with PVAc adhesive
- Lamination of heat treated spruce with different adhesives
- Bonding of heat treated beech with different PVAc adhesives

2.1. Influence of heat treatment of spruce on bonding with PVAc adhesive

The spruce (*Picea abies* Karst) wood lamellas were heat treated at five temperatures: 150, 170, 190, 210 and 230 °C. Lamellas were planed prior to bonding to ensure a flat and fresh surface. Cold-setting polyvinyl acetate (PVAc) adhesive (D4 class, Rakol GXL 4) was used for bonding. The application rate of the adhesive was 180 g/m². Bonding of small laminated beams was carried out for 60 minutes in a hydraulic press at room temperature and pressure of 1 N/mm². Test specimens were cut out of the laminated beams for evaluation of bond performance. The shear strength of adhesive bonds was tested according to standard EN 392 (dry specimens), where half of the specimens were soaked for 24 h in water before testing to evaluate the water resistance of adhesive bonds [7].

2.2. Lamination of heat-treated spruce with different adhesives

Control (untreated) and heat treated at 210 °C spruce wood lamellas were prepared. Four cold setting wood adhesives were used for bonding: polyvinyl acetate (PVAc), Mekol D4; emulsion polymer isocyanate (EPI), Casco adhesives; polyurethane (PUR), Mitopur E45; and melamine-urea-formaldehyde (MUF), Casco adhesives. The application rate of the adhesive was 180 g/m^2. Bonding of four lamellas into a small beam was carried out in a press at room temperature and pressure of 1 N/mm^2. A pressing time of 1 hour was used in the case of the PVAc and PUR, and 3 hours in the case of the MUF and EPI adhesives. The shear strength of the adhesive bonds was measured according to the standard EN 392 - conditioning in a standard climate at 65 % RH and 20 °C (dry), whereas half of the samples were soaked in water for 24 hours before testing (wet).

2.3. Bonding of heat treated beech with different PVAc adhesives

Control (untreated) and heat treated at 210 °C beech (*Fagus sylvatica* L.) wood lamellas were bonded with six PVAc adhesives of the similar quality, yet produced by different manufacturers: Falco-lit D3 W91, Kleiberit 303, Mekol 1130, Multibond EZ-1, Patex Wood D3 and Rakoll GLX-3. The application rate of the adhesive was 200 g/m^2. Bonding of two lamellas together was carried out for 30 minutes in a press at room temperature and at a pressure of 4 N/mm^2. The shear specimens were prepared according to EN 205 and tested according to EN 204 on the universal testing machine. Three pre-treatments were carried out prior shear tests:

- Dry (7 days in standard climate)
- Dry-Wet (7 days in standard climate and 4 days in water)
- Dry-Wet-Dry (7 days in standard climate, 4 days in water and 7 days in standard climate)

3. RESULTS AND DISCUSSION

3.1. Influence of heat treatment of spruce on bonding with PVAc adhesive

The shear strength (f_v) and percentage of wood failure (WF) of an adhesive bond of the specimens bonded with the PVAc adhesive are shown in Table 1 [7]. The shear strength of the PVAc adhesive bonds decreased with an increasing degree of thermal modification of the wood. Percentage of wood failure of dry specimens was not affected with heat treatment up to 170 °C, but then decreases significantly at higher temperatures of thermal modification. The wood failure decreased with shear strength after 24 h of soaking in water, which suggests reduced adhesion and cohesion.

Table 1: Shear strength and wood failure of PVAc adhesive bonds

Temperature of heat treatment [°C]	Dry specimens		24 h in water	
	f_v [N/mm^2]	WF [%]	f_v [N/mm^2]	WF [%]
Control	9,09	100	2,58	43
150	8,62	100	3,43	54
170	7,72	100	3,03	85
190	8,40	99	3,02	77
210	4,96	82	2,04	44
230	4,30	50	1,41	18

3.2. Lamination of heat treated spruce with different adhesives

The shear strength of the PVAc adhesive bonds of the specimens made of heat treated wood at 210 °C (HT210) was significantly lower than that of the control specimens (Table 2). This was evident for both the dry and the wet specimens. PVAc adhesive is a non-structural water-based adhesive, with low resistance to moisture and water, so that the presented results were as expected. The shear strength of the PUR, EPI and MUF adhesive bonds was not significantly affected by the heat treatment of the wood. The specimens made of heat treated wood exhibited similar shear strength to that of the control specimens. This was true for both the dry and the wet specimens. Wood failure was always 100 % in the case of the dry specimens, regardless of the type of adhesive used for bonding. After immersion in water for 24 hours, the shear strength of the all the adhesive bonds was significantly reduced. In the case of the wet specimens wood failure was decreased as compared to the dry specimens, except for the specimens bonded with MUF adhesive, where the wood failure remained 100 % [7].

Table 2: Shear strength and wood failure of the PVAc, PUR, EPI and MUF adhesive bonds

Adhesive and pre-treatment		Property	Control	HT210
PVAc	Dry specimens	Shear strength [N/mm^2]	8,9	5,8
		Wood failure [%]	100	100
	24 h soaking in water	Shear strength [N/mm^2]	4,4	2,8
		Wood failure [%]	93	92
PUR	Dry specimens	Shear strength [N/mm^2]	9,1	9,3
		Wood failure [%]	100	100
	24 h soaking in water	Shear strength [N/mm^2]	4,3	6,1
		Wood failure [%]	62	88
EPI	Dry specimens	Shear strength [N/mm^2]	8,3	8,9
		Wood failure [%]	100	100
	24 h soaking in water	Shear strength [N/mm^2]	4,23	3,9
		Wood failure [%]	78	80
MUF	Dry specimens	Shear strength [N/mm^2]	8,2	6,9
		Wood failure [%]	100	100
	24 h soaking in water	Shear strength [N/mm^2]	4,7	5,1
		Wood failure [%]	100	100

3.3. Bonding of heat treated beech with different PVAc adhesives

Heat treated beech wood did not bond with PVAc adhesives as well as the untreated beech wood. For the Dry specimens, the adhesive bonds of untreated beech wood had the shear strength from 12,8 to 15,6 N/mm^2 (Figure 1). On the other hand, the adhesive bonds of heat treated beech wood had lower shear strength that is from 5,8 to 11,7 N mm^2. For the Dry-Wet specimens, the shear strength of adhesive bonds deceased significantly compare to Dry specimens (Figure 2). In this case, the shear strength of adhesive bonds of the untreated beech wood was from 0,6 to 2,7 N/ mm^2, whereas the shear strength of the heat treated beech wood was lower from 0,4 to 2,4 N/ mm^2. For the Dry-Wet-Dry specimens, the shear strength of the untreated beech wood was from 5,9 to 11,1 N/mm^2, whereas the shear strength of the heat treated beech wood was lower from 2,0 to 8,0 N/ mm^2 (Figure 3).

There was a great difference in shear strength of the adhesive bonds due to the use of different PVAc adhesives. The best bonding results of untreated beech wood were obtained by using PATTEX WOOD D3 and MEKOL 1130 adhesives. When bonding heat treated beech wood, the best results were obtained using RAKOL GLX 3 and FALCO-LIT D3 W91 adhesive.

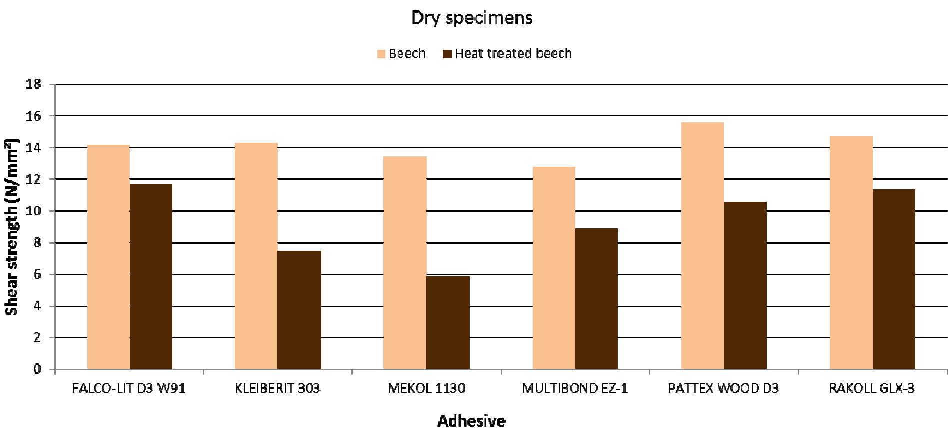

Figure 1: Shear strength of PVAc adhesives bonds for control and heat treated beech (Dry specimens)

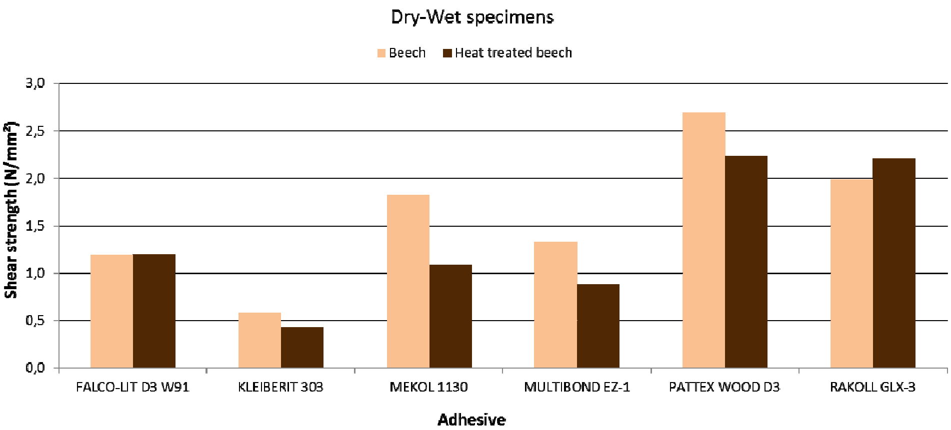

Figure 2: Shear strength of PVAc adhesives bonds for control and heat treated beech (Dry-Wet specimens)

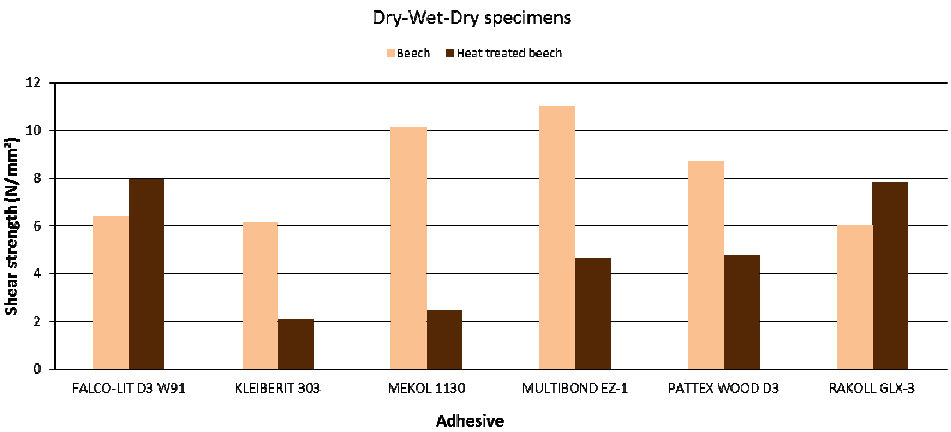

Figure 3: Shear strength of PVAc adhesives bonds for control and heat treated beech (Dry-Wet-Dry specimens)

4. CONCLUSIONS

It was found that the shear strength of the PVAc adhesive bonds decreased with a higher degree of heat treatment of spruce wood. The results of the dry specimens showed that the shear strength of the PVAc adhesive bond of heat treated spruce specimens decreased significantly compared to the control specimens, whereas the shear strength of the EPI, PUR and MUF adhesive bonds was not significantly affected by the thermal modification. After soaking in water the shear strength of the all the bonded specimens dropped significantly compared to the initial dry strength. It was also found that heat treated beech wood did not bond with PVAc adhesives as well as the untreated beech wood. There was also a great difference in shear strength of the adhesive bonds due to the use of different PVAc adhesives.

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4. REFERENCES

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