

# Comparison of Bonding Performance Between Plywood and Laminated Veneer Lumber Induced by High Voltage Electrostatic Field.

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**Abstract.** High voltage electrostatic field (HVEF) was applied in order to improve wood surface characteristics, bonding and mechanical properties of wood composites. Masson pine (*Pinus massoniana* Lamp.) plywood and laminated veneer lumber (LVL) were selected in this study. Surface characteristics were conducted by the electron spin resonance (ESR) and X-ray photoelectron spectra (XPS). Bonding interphase and mechanical properties were investigated by fluorescence microscopy and vertical density profile (VDP), bonding strength, wood failure ratio, MOE and MOR. The results indicated that more increments were obtained in free radicals, O/C ratios and C2-C4 components. This is because electrons broke more wood chemical groups and new ions occurred among wood surface under HVEF. Significantly decreased PF adhesive penetration depth (PD) and increased density at bonding interphase was achieved in HVEF treated composites. More decrease of PD and increment of density were observed in plywood than that of LVL. This was attributed to cross linked wood fibers among bonding interphase in plywood. Mechanical properties of bonding strength, wood failure ratio, MOE and MOR were significantly increased under HVEF treatment both for two composites. Higher bonding strength, MOE and MOR were obtained in plywood and their increments were as 98.53%, 33.33%, 18.55% and 12.72%.

## 1 Introduction

Wood composites such as plywood, LVL, Laminated strand lumber (LSL) and cross laminated timber (CLT) etc. play a significant role in forest product industry. They are widely utilized in interior decoration, wood structure construction and transportation domain [1-3]. However, there are some queries occurred when these wood engineering products were utilized, including low bonding strength, poor bonding interphase and mechanical properties.

A large proportion of studies have been investigated the bonding and mechanical properties of various wood composites. Some methods mainly focused on the modification of wood surface characteristics. Treatments of plasma, magnetic field, corona discharge and acid-alkali were used in order to improve wood surface energy and wettability [4-7]. However, these mainly methods were concentrated on the chemical properties of wood fibers, and anisotropic micro-structure of wood was not taken into consideration. Anisotropic porous structure of wood has significant influence on adhesive penetration property [8]. So, bonding property was determined by surface chemical properties and wood porous structure.

Other studies were conducted in order to improve mechanical properties. These methods mainly including nano-fiber, carbon fiber and biomass fiber reinforcement

[9-12]. These fibers among bonding interphase merely cross linked with wood surface fibers and they have few increased chemical reactions with wood chemical bonds during the procedure. Bonding strength was mainly determined by chemical groups among wood fibers and reactions of wood chemical bonds and the adhesive [13, 14].

HVEF treatment was a effective method to increase wood surface properties and bonding properties [15, 16]. Free electrons among anisotropic wood were triggered under HVEF treatment and they broke more chemical groups and new ions among wood surface when collided with each others [17]. As a result, the surface polarization was significantly enhanced and more reactions of wood chemical groups and adhesive could be obtained among bonding interphase during hot press procedure. Convection, transportation and spreading morphology of adhesive were observed to be new pattern and different structure by the HVEF and adhesive kinetics was significantly effected by HVEF [18]. Based on the above-mentioned, HVEF treatment has a significant effect on wood surface and bonding properties. There are some other queries to be investigated.

In this study, wood composites of plywood and LVL were selected and treated under HVEF treatment. Surface characteristics were measured by ESR and XPS;

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adhesive distribution among bonding interphase was detected by micrographs and VDPs; mechanical properties including bonding strength, MOE and MOR were obtained. The comparison of surface and bonding properties between HVEF-treated composites and the control ones were conducted and the difference of HVEF-treated plywood and LVL properties was also investigated.

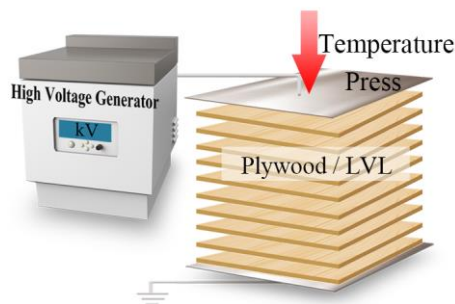


Fig. 1. Diagram for HVEF device and wood composites.

## 2 Material and experiment

### 2.1. Material

Veneers of Masson pine (*Pinus massoniana* Lamp.) with the dimension of 400 mm × 400 mm × 2.5 mm (length × width × height) were selected in this study without any defects. They were fabricated in a company in Jiangsu province. Veneers were oven dried at 103°C for two days and reach to a stable moisture content of 5 ± 3 %. Phenol formaldehyde adhesive (PF) was prepared with the ratio of 2:1 and the solid content is 45% (359 mPa·s, 20°C).

### 2.2 HVEF-Treated composites

Plywood (0°, 90°, 0°, 90°, 0°, 90°, 0°, 90°, 0°) and LVL composites were prepared by nine veneers with the PF adhesive of 150 g/m<sup>2</sup> for each surface of veneer. After assembled, composite was put in the electrostatic field within the hot press. The electrostatic field was comprised by two aluminium plants, one is connected with the high voltage and the other with the ground as shown in Figure 1 (JT207K-1, China). The voltage of 60 kV was selected and the treating time was the same as hot press time (20 min). The press temperature was 145°C during the treatment.

### 2.3 Surface characteristics measurements

ESR treatment (JES-FA200, Japan) was applied after HVEF treatment. Treating time was 20 min and the treating temperature was 145°C. The dimension for Masson pine samples was 43 mm × 2.5 mm × 2.5 mm. All the samples were dried to MC=3%. Ten repetitions were conducted for each condition.

XPS measurement (UltraDLD, England) was utilized and wood powders of 20 mesh were prepared. The

treating condition was the same as ESR measurement. C1s and O1s elements were investigated in this study.

## 2.4 Mechanical properties measurements

Fluorescence microscopy (BX51, Japan) was utilized in order to investigate the adhesive penetration depth among bonding interphase. Slices were cut from plywood and LVL composites and micrographs were obtained under the light of UV source.

VDPs measurement was conducted by the device of X-ray. The dimension of composite samples was 50 mm × 50 mm × 20 mm.

Mechanical properties including bonding strength, wood failure ratio, MOE and MOR were investigated by the universal machine (Suns, China). The measurement was according to the EN 314-1 and the EN-310. Ten repetitions were conducted for each condition.

## 3 Results and discussions

### 3.1 Surface properties of Masson pine

Free radicals of Masson pine were investigated by ESR spectrogram and the results were as shown in Figure 2. After treated by HVEF, free radicals were significantly increased. This is due to chemical groups (CH<sub>3</sub>O-, -C=O- and -OH) broken by electrons under HVEF. More broken chemical groups and new ions occurred on wood surface [19]. Change ratios of free ratios did not vary with treating times selected in this study. This can be explained that a certain amount of electrons were triggered by HVEF treatment and they collided each others and broke a certain extent of chemical bonds involved in wood surface [19, 20].

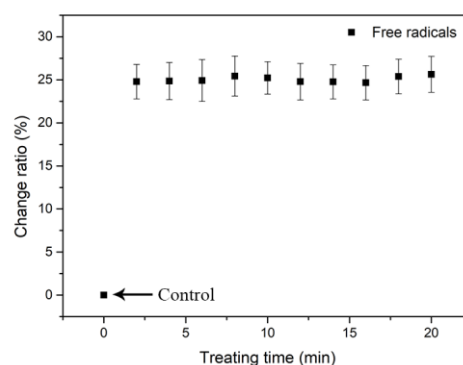
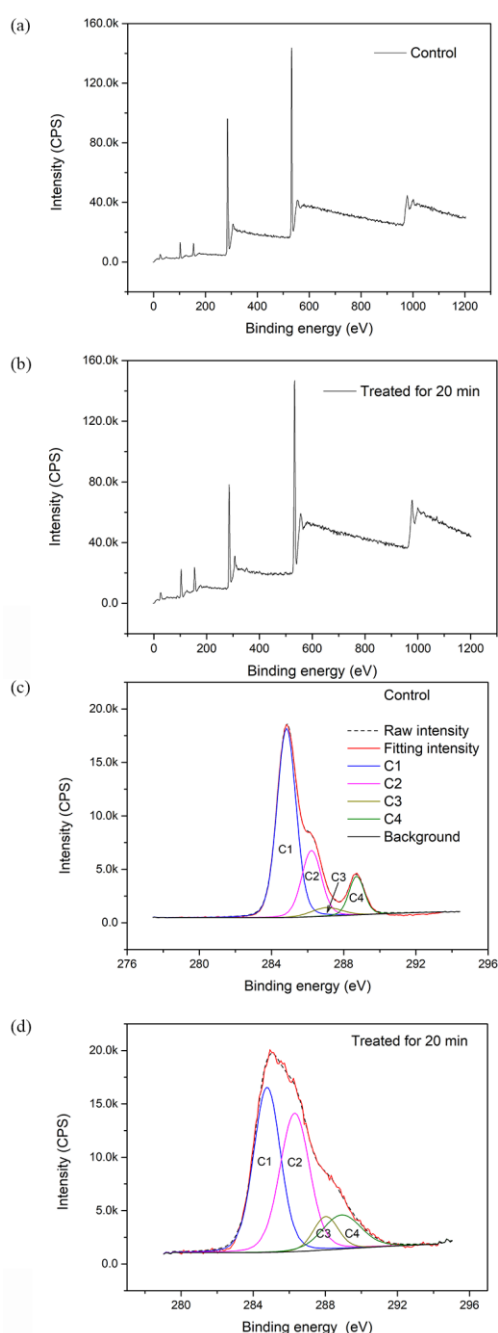


Fig.2. Free radicals of treated Masson pine compared with control ones.

XPS spectra was utilized in order to analyze qualitatively chemical elements changes among wood surface including oxygen and carbon. As observed in Figure 3 (a) and (b), from the whole range of the spectra, the C1s and O1s were signed and the O/C ratios were calculated in Table 1. Significant increment of O/C ratio was observed and it increased by 34% after treated by HVEF. This result indicated that chemical groups contained with oxygen were increased on wood surface.

This result was attributed to that triggered electrons broke more air molecules and chemical groups of wood surface. These broken groups concentrated on wood surface and higher degree of oxidation was obtained [21, 22].

As observed from the part of spectra in Figure 3(c) and (d), the components of C1 to C4 were signed respectively. C1 component represents the variation of lignin content. The components of C1 to C4 represents chemical groups containing oxygen elements and represents cellulose and hemi-cellulose. From Table 1, HVEF treatment induced significant changes on C1 to C4 components. The C1 component obviously decreased after treatment. In contrast, the C2 to C4 components were significantly enhanced by 39%, 149% and 97% respectively. These results were because lignin content degraded under HVEF and higher degree of oxidation was achieved among wood surface.



**Fig. 3.** O/C ratios and C1-C4 components of Masson pine under HVEF treatment and compared with control.

**Table 1.** XPS spectra for treated Masson pine samples compared with the control.

Masson pine			
	Control	Treated	Δ(%)
<b>C1<sub>s</sub> (%)</b>	71.06	65.70	/
<b>O1<sub>s</sub> (%)</b>	22.94	28.30	/
<b>O/C</b>	0.32	0.43	34%
<b>C1(%)</b>	64.46	41.43	-36%
<b>C2(%)</b>	22.76	31.54	39%
<b>C3(%)</b>	3.53	8.78	149%
<b>C4(%)</b>	9.26	18.25	97%

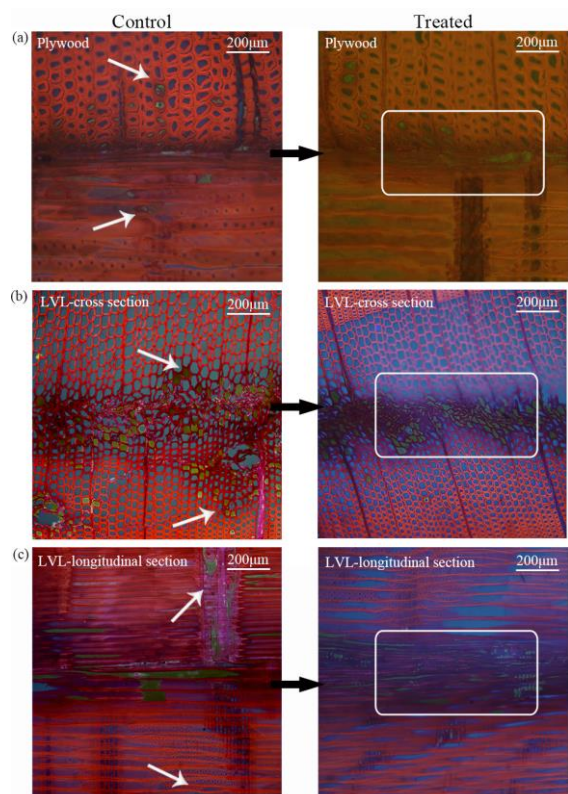
### 3.2 PF adhesive distribution

The PF adhesive penetration depth (PD) and the density of bonding interphase of treated composites were investigated and compared with the control plywood and LVL samples. The PF adhesive presents the green color under UV light and wood tissue presents the orange color [16].

For the control plywood, the adhesive distribution involved in its bonding interphase was irregular and the PF PD was significantly nonuniform along with the wood rays from cross and longitudinal sections in Figure 4(a)-control. This was due to anisotropic pore structure leading to variety of PF flowing resistance in wood. The average PF PD was calculated as 1090 μm based on the control plywood micrographs. After duration of the HVEF treatment, the adhesive distribution was uniform from bonding interphase and the PF PD was decreased significantly. Average treated PD was calculated as 258 μm. This result was because more triggered free radicals and broken chemical bonds occurred on wood surface provided more reactions with PF.

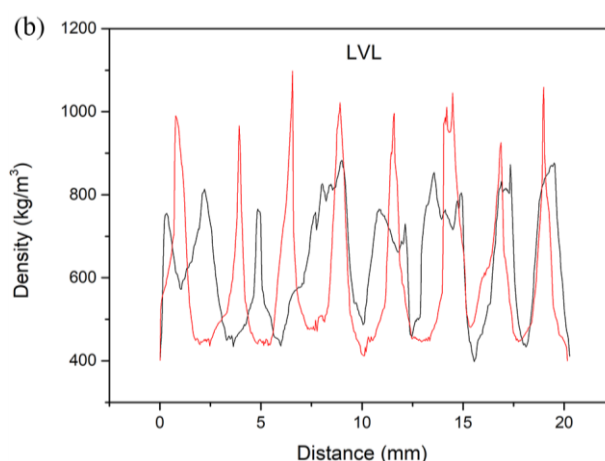
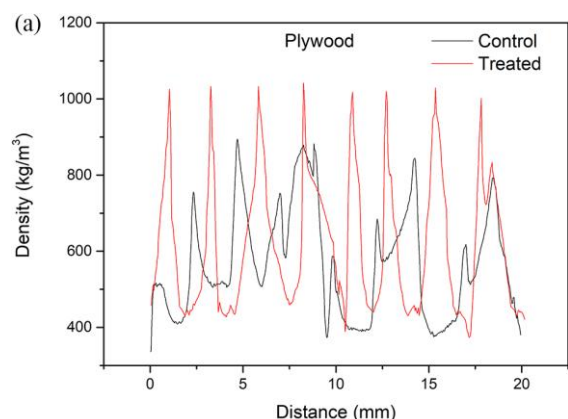
Micrographs of LVL cross and longitudinal sections were displayed in Figure 4(b) and (c). For the control graphs, wood structure was symmetrical by the bonding line but the adhesive distribution was also disorder along wood rays from cross and longitudinal sections. The average adhesive DP was 1187 μm. For treated samples, the PF PD was calculated as 322 μm. PF PD was significantly decreased after HVEF treatment and the adhesive distribution along wood rays was uniform and orderly from both sections. This result was attributed to the same reason for treated-plywood samples. The difference of adhesive PD between treated-plywood and -LVL for was because wood fiber was vertically and

horizontally cross-linked at bonding interphase of plywood and higher flow resistance was obtained.



**Fig. 4.** Micrographs for plywood and LVL under HVEF treatment and compared with control ones.

The density distributions for plywood and LVL were as shown in Figure 5. For control VDPs, the max density at bonding interphase was less than 900 kg/m<sup>3</sup> and the distribution was nonuniform at each bonding interphase. After HVEF treatment, the density at each bonding interphase was significantly increased both for plywood and LVL. The average density at bonding interphase for plywood was 1025 kg/m<sup>3</sup> and for LVL was 1012 kg/m<sup>3</sup>. The density distribution at each bonding interphase were more narrowed than the control both for plywood and LVL. Higher average density at bonding interphase was obtained in plywood because more decreased PF PD was achieved as explained in Figure 4.



**Fig. 5.** VDPs for treated plywood and LVL samples compared with control.

### 3.3 Mechanical properties

Mechanical properties including bonding strength, wood failure ratio, MOE and MOR for plywood and LVL were investigated and compared with the control samples as shown in Table 2. For the control samples, the bonding strengths and wood failure ratios for both plywood and LVL were very low and higher mechanical properties were obtained in plywood than that of LVL. After treatment, significant increments of bonding strength, wood failure ratio, MOE and MOR were observed with the increment of 108.86%, 54.55%, 26.75% and 17.58% for plywood and 98.53%, 33.33%, 18.55% and 12.72% for LVL. These results were attributed to more decreased DP and increased density among bonding interphase for both composites. Higher increments were obviously achieved in plywood than that of LVL. This was because HVEF induced more decreases on DP and more increments on density at bonding interphase of plywood.

**Table 2.** Mechanical properties for plywood and LVL compared with the control ones.

Species	Properties	Control	Treated
Plywood	Bonding strength (MPa)	0.79 (0.10)	1.65 (0.12)
	Wood failure ratio (%)	55 (5.00)	85 (4.50)
	MOE (⊥, GPa)	12.23 (0.80)	15.50 (1.02)
	MOR (⊥, MPa)	45.06 (0.95)	52.98 (1.05)
LVL	Bonding strength (MPa)	0.68 (0.09)	1.35 (0.15)
	Wood failure ratio (%)	60 (5.50)	80 (5.00)
	MOE (⊥, GPa)	11.43 (0.77)	13.55 (0.89)
	MOR (⊥, MPa)	43.57 (0.82)	49.11 (0.88)

## Conclusions

HVEF treatment has a significant influence on surface characteristics, bonding and mechanical properties of wood composites including plywood and LVL. Free radicals, O/C ratios and C1s (C2-C4) components were obviously increased after HVEF treated. Decreased adhesive PD and increased density at bonding interphase were also observed because of improvements of surface characteristics. Higher increment of density and decrease of adhesive PD were obtained in plywood than that of LVL. The average density at bonding interphase for plywood was 1025 kg/m<sup>3</sup> and for LVL was 1012 kg/m<sup>3</sup>. This is attributed to wood fibers crossed linked among bonding interphase in plywood. Mechanical properties including bonding strength, MOE and MOR were significantly enhanced both for two composites and higher increments were involved in plywood respectively as 98.53%, 33.33%, 18.55% and 12.72%. Wood macroscopic property of grain angle contributed great to HVEF treatment.

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