

Modified Hybrid Poplar for Structural Composites

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ABSTRACT

The viscoelastic thermal compression (VTC) method for wood densification was used to produce two types of structural composites from hybrid poplar (*Populus sp.*). One method applied the VTC process to wood strands prior to manufacture of an oriented strand composite, while the other method applied the VTC process to a conventional oriented strand composite that was already manufactured. No significant problem with bonding VTC wood was observed and the VTC process did not disrupt the bonding of phenol-formaldehyde adhesive. Both methods improved bending strength and stiffness in comparison to control specimens.

INTRODUCTION

One approach for modifying wood properties is by mechanical compression perpendicular to the grain. This approach increases the density and typically improves stiffness, strength, and hardness. Elevated temperature and steam are usually applied prior to densification to soften the wood. After compression, extended thermal treatment may be used to improve resistance to water adsorption. Viscoelastic Thermal Compression (VTC) is one method of increasing the density of wood by means of mechanical compression perpendicular to the grain under conditions of dynamic temperature and steam pressure (Kamke and Sizemore 2008). The VTC process has been shown to be effective for processing thin lamina of solid wood and veneer (Kamke 2006). This project investigated the use of the VTC process to modify wood for use in structural composites. The focus was on wood strand composites.

MATERIALS AND METHODS

Hybrid poplar, a cross between eastern and black cottonwood (*Populus deltoides* and *Populus trichocarpa*) and widely cultivated in North America on intensively managed plantations, was used. Strands were cut from boards using a guillotine veneer slicer to produce strands with length of 15 cm and width of 2.5 cm. Thickness was controlled to either 2.2 mm or 0.65 mm. The thicker strands were processed with VTC while the thinner strands were used as is. The 2.2 mm thick strands were densified using a modified VTC schedule. The initial average moisture content of the strands was approximately 72%. The VTC schedule involved placing a specimen between heated platens and exposing it to 170 °C, 860 kPa saturated steam for 3 min prior to compression; mechanical compression at 2 MPa was then performed for 2 min; steam pressure was released to atmospheric pressure; the press was then opened for 90 seconds to allow rapid release of moisture before final compression at 4 MPa to target thickness

of approximately 1 mm; the specimens were then cooled below 100 °C before the platens were opened. The VTC press was configured to process 18 strands simultaneously. A total of about 2,000 VTC strands were produced. Two types of strand composites were manufactured – pre-pressed VTC strand composites and post-pressed VTC strand composites. The pre-pressed VTC strand composite was made from a mix of VTC strands and non-VTC strands. The VTC strands were oriented in one direction in the top and bottom layer of the strand mat. Non-VTC strands, with random orientation, were used in the core. The weight fraction of VTC strands was either 20% or 40% of the total mat weight. For comparison, composites with non-VTC strands were made that had top and bottom layer orientation equal to either 20% or 40% based on total mat weight. In addition, some strand composites with no strand orientation were also produced. The target density for the pre-pressed VTC strand composites and control panels was 575 kg/m³. The thickness was 1.3 cm. The post-pressed strand composites were produced with no VTC strands and with random orientation. These mats were hot-pressed into panels with target density of 575 kg/m³ and thickness of 0.84 cm. Following hot-pressing, the composites were subjected to the VTC process for a final thickness of 0.46 cm. All mats were hot-pressed using a conventional press schedule in a laboratory press. A commercial blend of OSB face-layer phenol-formaldehyde adhesive was used (3.5% by weight) for all composites. The post-pressed VTC composites are to be used in the outer layers of a 3-layer panel. The core layer is to be random-oriented non-VTC strand board. At the time this manuscript was submitted these panels had not yet been tested. All strand specimens were stored at 25% relative humidity and 30°C until an equilibrium moisture content was reached before use in composite manufacture. A subset of strands (20 replications) were used to determine bending modulus in the oven-dry condition. A universal test machine was used in 3-point bending mode. Composites that were produced were stored at 20 °C and 65% relative humidity, until equilibrium was reached, prior to testing. Composites were tested in 3-point bending (ASTM 2004). Pre-pressed VTC strand composites were tested to failure. Post-pressed VTC strand composites were tested below the elastic limit so that they can be used to produce 3-layer panels (results not available at this time).

RESULTS AND DISCUSSION

Results for strand tests are shown in Table 1. The VTC process increased the strand density by an average of 93%. The bending modulus increased 73%. The VTC strands were flat and had a smooth texture.

Table 1: Density and bending modulus of non-VTC strands and VTC strands (20 replications). Tests were conducted in the oven-dry condition.

| Before VTC | | | | After VTC | | | |
|------------------------------|-----------|-----------|-----------|------------------------------|-----------|-----------|-----------|
| Density (g/cm ³) | | MOE (GPa) | | Density (g/cm ³) | | MOE (GPa) | |
| Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. |
| 0.44 | 0.0516 | 9.09 | 2.38 | 0.85 | 0.122 | 15.7 | 5.54 |

Results for the pre-press VTC strand composites are shown in Table 2. The simple process of orientation had the greatest impact on bending properties, as expected. For panels with no VTC strands, orientation of 20% of the strands (based on weight) increased the MOE and MOR by 55% and 22% respectively. Orientation of 40% of the non-VTC strands resulted in MOE and MOR increases of 73% and 34% respectively. Use of the VTC strands improved bending properties, but this effect was not as dramatic

as orientation. Adding 20% VTC strands by weight increased MOE and MOR by 7% and 8% respectively. A 40% VTC strand addition increased MOE and MOR by 25% and 17% respectively. Due to the high density of the VTC strands, there were very few of them in the composites with only 20% addition based on weight. Consequently, the VTC strands did not form a continuous layer. With 40% VTC strand addition a continuous layer was achieved. An examination of the broken specimens revealed most failures occurred at the gaps between VTC strands or fracture of non-VTC strands. Qualitative observation indicated that bonding of VTC strands with phenol-formaldehyde was adequate. However, failures tended to occur at the interface between VTC strands and non-VTC strands, indicating adhesive flow characteristics could be modified to be more compatible with this system. The increase in bending properties was achieved without increasing the overall density of the strand composite. The density profile through the thickness was modified. Conventional hot-pressing results in a greater density near the surfaces than the core, which is preferred when bending strength and stiffness are important. The pre-pressed VTC composite accentuates the density profile such that more wood substance is concentrated in the top and bottom surfaces. Table 2 shows that a slight increase in panel density (about 6%) was measured when VTC strands were added. This was due to the reduced amount of thickness recovery after hot-pressing the VTC composites. The pre-pressed VTC strand composites were thinner than the control specimens. From one perspective, one would expect the greater overall density to increase MOE. From another perspective, a thinner panel (core layer) means a smaller bending moment of inertia, and consequently a decrease of effective MOE for this non-homogeneous composite. Therefore, it is unclear how the slight density variation of the pre-pressed VTC strand composites influenced the MOE results.

Table 2: Properties of pre-pressed VTC strand composites (12 replications). Amount of strands oriented in surface layer based on total weight of panel.

| Treatment | Density (kg/m³) | | MOE (GPa) | | MOR (MPa) | |
|----------------------|-----------------------------------|-----------|------------------|-----------|------------------|-----------|
| | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. |
| No VTC, 0% oriented | 573 | 27.6 | 7.46 | 1.05 | 49.3 | 7.36 |
| No VTC, 20% oriented | 587 | 41.2 | 11.6 | 1.57 | 60.1 | 9.18 |
| VTC, 20% oriented | 623 | 42.5 | 12.4 | 1.72 | 64.9 | 9.34 |
| No VTC, 40% oriented | 617 | 33.7 | 12.9 | 1.10 | 66.1 | 9.27 |
| VTC, 40% oriented | 658 | 43.3 | 16.1 | 2.47 | 77.1 | 7.60 |

VTC processing increased the MOE of the post-pressed VTC strand composites by 150%. The density increase was 102%. No deterioration of the phenol-formaldehyde adhesive bond was detected even though the composite was subjected to saturated steam at 170 °C for 3 minutes, followed by a rapid decompression. This post-pressed method of VTC treatment dramatically increased the overall density of the composite. However, the intent is to use the post-pressed VTC strand composite as a lamina in a layered composite. The layered composite would also include low density strand lamina, so the overall density would be significantly less than the post-pressed VTC strand composite.

Table 3: Properties of post-pressed strand composites, with random orientation, before and after VTC process (15 replications).

| Before VTC | | | | After VTC | | | |
|------------------------------|-----------|-----------|-----------|------------------------------|-----------|-----------|-----------|
| Density (kg/m ³) | | MOE (GPa) | | Density (kg/m ³) | | MOE (GPa) | |
| Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. |
| 511 | 48.1 | 3.60 | 0.592 | 1032 | 57.5 | 9.02 | 1.45 |

CONCLUSIONS

The VTC process can be used to enhance the bending properties of strand composites made from hybrid poplar. Individual strands may be densified and blended with non-VTC strands to increase MOE and MOR by up to 25% and 17%, respectively, with the addition of 40% by weight of VTC strands. This result was demonstrated without increasing the overall density of the composite. Post-pressed VTC strand composites can achieve even greater improvements in bending strength and stiffness. However, the overall density increases significantly. Phenol-formaldehyde performed well as an adhesive for VTC wood and withstands the pressurized steam environment used in the VTC process. However, improvement in adhesive formulation for this application is probably possible.

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