# The Research on Bamboo-wood Corrugated Sandwich Panel

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**Abstract**

The physical and mechanical properties of Bamboo-wood corrugated Sandwich Panels (BCSP) relevant for nonstructural Panels were studied. The Bamboo-wood corrugated Sandwich Panels consisted of 2 face layers and the core particleboard that was made of low-value biomass material (bamboo and wood particles) through hot-mold pressing. The modulus of rupture (MOR), the modulus of elasticity (MOE) and the compressive strength (CS) were determined. The 3-layer composites were also prepared from the corrugated core layer and 2 face layers, and tested in three-point bending and compressive strength. A maximum value of the properties was obtained for bamboo core particleboard and 2 MDF face panels. It was observed that the bending and compressive properties of BCSP (MOR, MOE and CS) were significantly improved due to the pressure, temperature and time of the manufactured sandwich panels. Effect of pressure on physical and mechanical properties of urea-impregnated biomass corrugated composites was the most crucial. It was found that the compressive strength (CS) of composites decreased when pressing time was extended from 7 to 9min, whereas the modulus of rupture (MOR) and the modulus of elasticity (MOE) did not decrease. The bonding and compressive performance of the biomass corrugated composites with UF adhesive was comparable with or better than in the case of the biomass cellular board.

***Keywords:*** Bamboo-wood corrugated Sandwich Panels; physical and mechanical properties; bamboo particles; MDF.

## Introduction

The optimized structure with the corrugated structure is rational bearing structure, a favorable compressive strength and shear strength can obtained through applicable Structural Design (Er 2008). Compared with cellular structure, the shear strength of corrugated structure is three to seven times in YZ-direction (Xiong 2001). The current commercial products for Packaging, such as carton, enclosure Material of refrigerator wagon camping house and the conventional corrugated forming method, included roll forming, bending forming and Pull forming (He 2004).

In the present work, some wood-bamboo-based sandwich panels with low-value fiberboard were manufactured with different thickness, core density, and face materials. A three-point bending test was conducted, and the compressive strength (CS) was determined, which was also important for structural calculations.

Pressing factors are critical for core particleboard manufacture, because the temperature, the pressure and the time play a dominant role in mechanical performance. The optimization of laminated plate structures have been considered by a number of authors (Jiang 2002, Gao 1997), but the optimization of wood-bamboo- based sandwich panels, and particularly with corrugated core, appears to be much less well studied. Therefore, the optimum designs of some virtual wood-bamboo-based sandwich structures were analyzed by considering the designs of the manufactured panels.

## Materials and Methods

**Face and core materials.** For core materials, bamboo particle, wood flake and wood fiber from factory milling waste were prepared, which would be produced corrugated core through hot-mold pressing. For face materials, plywood (PW), medium-density fiberboard (MDF) and bamboo parallel strand lumber (BPSL) were prepared. The PW was commercially produced from hardwood veneer with a thickness of 5 mm and MOR of 18 MPa. The MDF was commercially produced from hardwood fiber with a thickness of 5 mm and MOR of 34 MPa. The BPSL was commercially produced from bamboo pieces with a thickness of 5 mm and MOR of 67 MPa.

**Manufacture of sandwich panels.** Nine types of Bamboo-wood Sandwich Panel with corrugated core were manufactured as listed in Table 1. Sandwich panels with a target thickness of 18 mm at three Layers (2 face Layers and a corrugated core layer) as shown in Figure 1.

*Table 1 Experimental geometric data of the manufactured sandwich panels*

| No. | Face | Core | $MOR_{\parallel}$ (MPa) | $MOR_{\perp}$(MPa) | $MOE_{\parallel}$ (MPa) | $MOE_{\perp}$(MPa) | CS(MPa) |
|---|---|---|---|---|---|---|---|

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | ① | Ⅰ | 9．03 | 7．77 | 983 | 660 | 1．88 |
| 2 | ① | Ⅱ | 12．12 | 10．67 | 1304 | 919 | 3．32 |
| 3 | ① | Ⅲ | 16．52 | 14．11 | 2904 | 2244 | 2．54 |
| 4 | ② | Ⅰ | 22．21 | 20．53 | 2042 | 1402 | 1．64 |
| 5 | ② | Ⅱ | 17．81 | 15．61 | 2111 | 1753 | 3．40 |
| 6 | ② | Ⅲ | 24．37 | 19．81 | 2736 | 2571 | 5．06 |
| 7 | ③ | Ⅰ | 29．08 | 23．85 | 1958 | 1200 | 1．24 |
| 8 | ③ | Ⅱ | 20．39 | 11．08 | 4052 | 600 | 1．22 |
| 9 | ③ | Ⅲ | 38．53 | 14．86 | 5207 | 707 | 3．60 |

The data are average values of the specimens for the mechanical property test. ①, 5 mm PW; ②, 5 mm MDF; ③, BPSL; Ⅰ, 5 mm corrugated core of wood fiber ; Ⅱ, 5 mm corrugated core of wood flake; Ⅲ, 5 mm corrugated core of bamboo particle; MOR, longitudinal Modulus of Rupture of panel; MOR, transverse Modulus of Rupture of panel; MOE, longitudinal modulus of elasticity of panel; $MOE_{\perp}$ transverse modulus of elasticity of panel; CS, compressive strength.

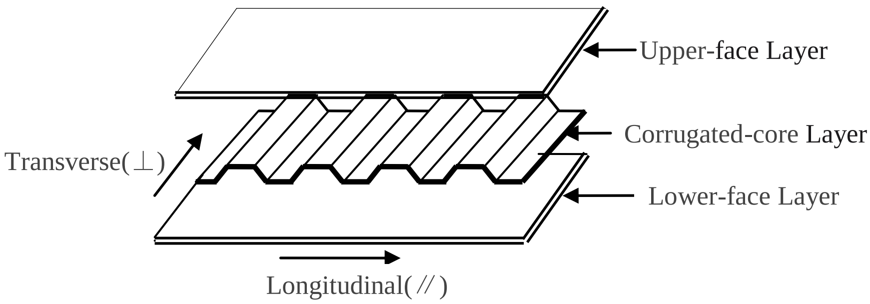



*Figure 1 Structure schematic of sandwich panel*

The manufacturing procedure of sandwich panels was as follows. The core material was put into a blender and the commercial adhesive of urea-formaldehyde (UF) was sprayed into the particle using a spray gun during material the cycle. The resin content was 9% solid resin of UF based on the oven-dried particle weight. The particle was formed into corrugated core in a size of 400 (width) × 400mm (length) through hot-mold pressing by using a corrugated shape forming steel mold. All face materials were prepared in a size of 400 (width) × 400 mm (length). Before pressing, UF adhesive was spread on the back side of each face material at approximately 130 g/m2 on solid basis using a hard plastic hand roller. The face materials were then symmetrically placed on the top and bottom surfaces of corrugated core so that the grain of the face layer was parallel to the panel length direction (longitudinal direction of corrugated core).

The assembled slabs were pressed through a “hot into and hot out” hot-press molding and the process curve was shown in figure 2. In this study, three main pressing process factors (temperature, pressure and time) of hot-mold pressing were emphatic studied, three different levels were selected in each factor, and the L9 (34) orthogonal experiment design as shown in

Table 2 (the test specimens consisted of 2 MDF face-layers and the core-layer was made of bamboo particle) ( LI, 2005).

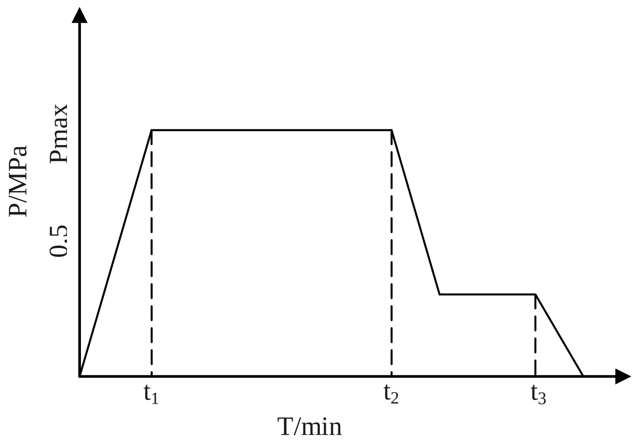



*Figure 2 Process curve of hot-press molding*

*Table 2 The orthogonal experiment factors and levels*

| level | temperature（T）/℃ | pressure（P）/MPa | time (t)/min |
|---|---|---|---|
| | factor | | |
| 1 | 150 | 2.5 | 5 |
| 2 | 160 | 3.0 | 7 |
| 3 | 170 | 3.5 | 9 |

**Testing methods**

Prior to conventional evaluation of the mechanical and physical properties, the specimens were conditioned at 20℃ and 65% relative humidity (RH) for at least 2 weeks. The panels were tested based on Test methods of evaluating the properties of wood-based panels and surface decorated wood-based panels (GB/T17657-1999).

All the panels were trimmed and cut into various test specimens as follows: 50 (width)×200 mm (length) for static bending; 100 (width)×100 mm (length) for compressive strength (CS). The static bending tests were conducted on four specimens from each treatment (total 36 samples), using a three-point bending test over an effective span of 150mm at a loading speed of 10 mm/min; four test specimens were prepared from each treatment (total 36 samples) for the CS. Comparison of property values of the Bamboo-wood Corrugated Sandwich Panel (BCSP) with Wooden Cellular Panel can describe the position of BCSP among the well-known nonstructural panels.

## Results and discussion

The experimental geometric data of BCSP are listed in Table 1. Results indicate that both bending and CS properties of BCSP, which consisted of 2 MDF face-layers and the core-layer made of bamboo particle, achieved optimal among experimental geometric data. The BCSP exhibited a better mechanical properties and was chosen as materials in orthogonal experiment.

Table 3 shows the test results of orthogonal experiment of the test specimens and these range analysis results are shown in Table 4. From the above results, the pressure of the manufactured sandwich panels was the most effective factor to improve the mechanical properties among the three factors. The temperature and the time of the manufactured sandwich panels had less significant effects on mechanical properties of the test specimens

*Table 3 The test results of orthogonal experiment*

| No. | T(℃) | P(MPa) | t(MPa) | MOR∥ (MPa) | MOR⊥ (MPa) | MOE∥ (MPa) | MOE⊥ (MPa) | CS (MPa) |
|---|---|---|---|---|---|---|---|---|
| 1 | 155 | 2.5 | 5 | 16.743 | 13.029 | 2270 | 2034 | 5.090 |
| 2 | 155 | 3.0 | 7 | 20.414 | 20.952 | 4723 | 2594 | 5.570 |
| 3 | 155 | 3.5 | 9 | 29.719 | 22.258 | 5746 | 3445 | 5.765 |
| 4 | 160 | 3.0 | 5 | 22.442 | 19.936 | 4769 | 2277 | 6.177 |
| 5 | 160 | 3.5 | 7 | 30.668 | 25.136 | 5947 | 3677 | 6.774 |
| 6 | 160 | 2.5 | 9 | 18.458 | 15.499 | 3077 | 2683 | 4.013 |
| 7 | 165 | 3.5 | 5 | 21.234 | 20.761 | 4380 | 2616 | 5.638 |
| 8 | 165 | 2.5 | 7 | 21.308 | 11.749 | 3845 | 2305 | 5.177 |
| 9 | 165 | 3.0 | 9 | 21.860 | 13.936 | 3266 | 2646 | 5.544 |

*Table 4 The range analysis of the process variables affecting to panel*

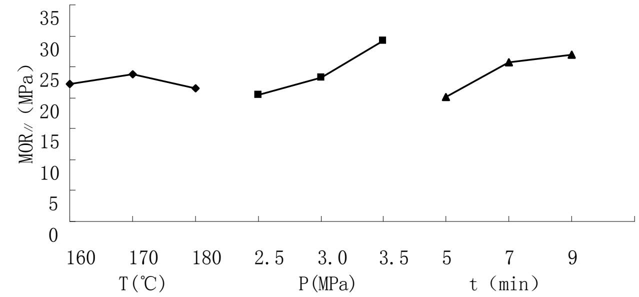
| Level | MOR∥(MPa) | | | MOR⊥(MPa) | | | MOE∥(MPa) | | | MOE⊥(MPa) | | | CS(MPa) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T | P | t | T | P | t | T | P | t | T | P | t | T | P | t |
| 1 | 22.292 | 20.503 | 20.140 | 18.746 | 13.426 | 17.909 | 4246 | 3064 | 3806 | 2691 | 2341 | 2309 | 5.475 | 4.760 | 5.638 |
| 2 | 23.856 | 23.239 | 25.797 | 20.190 | 19.608 | 20.612 | 4598 | 4253 | 4838 | 2879 | 2506 | 2859 | 5.655 | 5.764 | 5.840 |
| 3 | 21.467 | 29.207 | 27.012 | 15.482 | 25.385 | 19.898 | 3830 | 5358 | 4030 | 2522 | 3246 | 2925 | 5.453 | 6.059 | 5.107 |
| range | 2.389 | 8.704 | 6.872 | 4.708 | 11.959 | 2.703 | 768 | 2294 | 1032 | 357 | 905 | 616 | 0.202 | 1.299 | 0.733 |

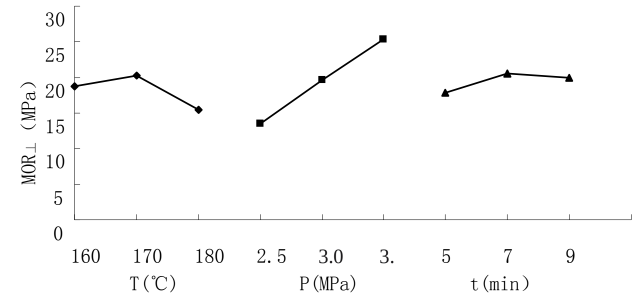
Figure 3 indicates that the temperature had a significant effect on panel plasticizing and adhesive curing. The bending and CS values of BCSP increased with the increase in temperature (150 ℃ to 160 ℃), which indicated that mechanical properties had a tendency to increase with increasing temperature. When the temperature of the slab increased, the adhesive viscosity decreased, bamboo material were heated to bate, and liquidity increased, all of which had more advantage to enhance the contact between the material and adhesive and improve the internal bonding strength.

Moreover, the increase of temperature was beneficial to the form of temperature gradient in the thickness direction of the panel, which caused the High-hard surface, and resulted in the increase of mechanics performance. However, a reverse trend was found in a higher temperature (160 ℃ to 170 ℃). The reduction in mechanical properties might be due to the following reasons: material degradation under high temperature, and even coking phenomenon lead to the increase of brittle surface. As a result, less value was being obtained.

Results of statistical analysis (Fig. 3) show that the pressure has a significant effect on the bending and CS properties. The effect on bending and CS values of BCSP was clearly observed. This was because the much closer contact between internal material and adhesive, the more improvement of the bonding strength. The trend of CS increase slowed when the pressure values reach over 3.0 MPa. The reason may be that the it can satisfy the needs of gluing between the strands. No significant effects were observed when the pressure increased. Additionally, the curing degree becomes a major factor influencing mechanical properties.

Figure 3 shows time factor has a significant effect on bending and CS values. The bending and CS strength of BCSP increase with increasing time (5min to 7min). The results indicate that the extension of time can promote curing of the glue to achieve a better mechanical properties within a certain range. The time values of the sandwich panels were in the range of 7 min to 9 min, MOR⊥、MOE⊥ and CS values of BCSP had a tendency to decrease with increasing pressing time because of degradation and embrittlement of bond line. Whereas the MOR‖ and MOE‖ values generally were not significantly affected. At different direction, the higher pressing time may play a subdominant role where mechanical properties are concerned during resin cured in the panels.



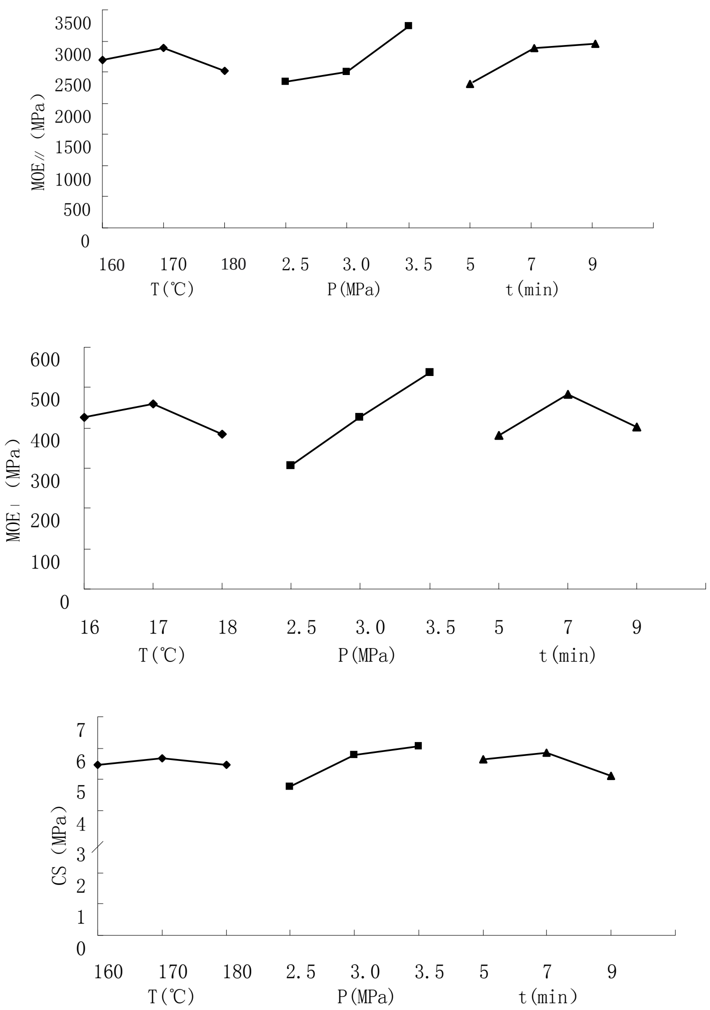



*Figure 3 Technology factors affecting to mechanical properties of BCSP*

## Conclusions

The manufacture of BCSP from corrugated strands of moso bamboo (Pyllostachys pubescens Mazel) appeared to be technically feasible. Strength properties were improved with increasing pressure mainly; Temperature and time had less significant effect on strength properties. The Optimum technologic parameters of BCSP manufacturing are as follows: 160 ℃ of temperature in core pressing, 3.0 MPa pressure in core pressing, 7 min time in core pressing. Compared to the commercial nonstructural products, BCSP showed superior strength properties. It is recommended that further research should be done to investigate other properties of BCSP, such as biological resistance, weather-ability, finishing properties, and fastener-holding capacity.

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