EFFECT OF TEMPERATURE AND TIME OF DIMENSIONAL STABILIZING PROCESS ON PROPERTIES OF SHAPE TRANSFORMED COMPRESSED WOOD

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SUMMARY
In the compressed wood production technology, the heat treatment for dimensional stability of compressed wood plays an important role as it reduces tension in the wood after shape transformed compressing. This study has mentioned the effects of temperature (160.170, 180, 190, 200, 210^{o}C) and duration (0.5, 2.5, 4.5, 6.5, 8.5h) of treatment of *Styrax tonkinensis* woodin a vacuum condition of 650mmHg. The results indicated that: i) When the heat treatment time increased, the recovery of set of compressed wood decreased and anti-swelling efficiency increased, which means the dimensional stability increased with the treatment time. That changes were reflected most clearly in the period from 0.5 - 4.5h. However, when the time exceeded 7.0h, the weight loss of compressed wood tended to halt. For temperature, when increasing it gradually in the treatment, the wood dimensional stability also rose up. When the temperature reached 200^{o}C, the dimensional stability redirected and halted. ii)In the process of dimensional stability treatment with high temperature, the compressed wood density slightly decreased and some of the mechanical properties of compressed wood also decreased, but those were still higher than untreated wood (uncompressed). In particular: Parallel compressed strength reduced with maximum speed at the beginning of the process (from 0.5 - 2.5h), then the effects of the temperature did not affect significantly and this stress was almost constant, especially since 6.5 to 8.5 hours; When extending the heat treatment time to stabilize the dimension of wood from 0.5 to 8.5h in vacuum condition with temperature of 210^{o}C, the tangential section's hardnesss (actually the outer surface) of 4-side compressed wood reduced inversely with treatment time.
Keywords: ASE, compressed wood, dimensional stability, Styrax tonkinensis, transforming shape.

I. INTRODUCTION

*Styrax tonkinensis*is fast growing plantation hardwood popularly used in Vietnam. Its wood has pinkish white color, heart wood and sap wood are differentiable; the wood basic density is 0.38-0.41g/cm^3. There have been several studies on utilization of *Styrax tonkinensis* in wood processing industry such as the study on producing fire retardant particleboard (Tran Van Chu, 2001), high quality particleboard (Hoang Tien Duong, 2003)... and especially, Tran Van Chu (2010) studied on density improvement of fast growing plantation hardwood used for construction material by compressing *Styrax tonkinensis* wood having large size and using HNO_3 to stabilize the dimension, Dang Xuan Thuc (2015) studied on utilization of *Styrax tonkinensis*as raw materials to produce laminated veneer lumber.

Compressed wood used in this study is a product made from core of Rotary-peeled of *Styrax tonkinensis* with round section diameter of 84mm. Through the technology of heating by microwave with frequency of 2450MHz (using National NN-C2000P) in the appropriate mode (depending on time and capacity of heat, moisture and weight of sample), round wood billet was 4-side compressed simultaneously in the mould which has the heating parts transforming the section into square having the basic size of each side of 60mm. Compression ratio was 36.31% at that time. To transformed shape be fixed, the most effective method is to reduce the inner stress after transformed shape compressing. Thus, after compressing, it should be conducted stabilizing compressed wood dimension in a state of wood still remaining compressed (in the mould), making shape-transformed wood has the degree of transformation and resistance to environmental conditions to be consistent with the technical requirements.

The calculation and selection processes of technological parameters were conducted through steps: The fisrt, selecting the heat treatment method in three ways: i) Heat treatment in convective circulatory environment (Air heating with oven Memmert UFB 40); ii) Heat treatment in the condition of lower pressure than atmospheric pressure: vacuum drying and high temperature (Vacuum heating with a vacuum oven Daiki VD200); iii) Moltalmetal heating: The equipment used is a heating panel (with the thermal power of 5KW). The second, selecting temperature at 3 levels: 150, 180 and 210^{0}C; and the processing time is changed from 1 - 24 hours (depending on temperature), the expected wood processing time temperature is counted from when the temperature of the processing environment reaches the processing temperature until the end of the process.

From experimental studies with single factor for reference, the author chose the method of heat treatment in a vacuum condition, 6 temperature levels and 6 time levels for compressed wood to transform (from round to square shape) with the compression rate of 36.31% from *Styrax tonkinensis*.

II. METERIALS AND METHODS

2.1. Materials

- *Styrax tonkinensis* – Pierre, 8 years old, harvested in Vinh Phuc province (Vietnam).
- The billet's round section had a diameter of 84 mm. Through the heating by microwave in the appropriate parameters (depending on time and capacity of heat, moisture and weight of sample), that billets were 4-side compressed simultaneously In the mould which has heating parts transforming the shape to square with size of each side (60mm). Compression ratio reached 36.31% at that time.

2.2. Equipments

The main equipments used in this study were: Microwave oven National NN-C2000P; Vacuum drying oven Daiki VD200; Climate chamber Jeiotech TH-G180L; Universal testing Mechanical MTS Qtest/25; the tools being used: Electronic Caliper Mitutoyo 0.001 mm; Analytical Balance Satorius BL 210…

2.3. Standards for testing

- Testing the recovery of set, weight loss and anti-swelling efficiency by Boiling test: Wood sample wassoaked in water for30 minutes in a vacuum condition then taken out and kept in the atmosphere in 210 minutes. The sample was soaked in a boiled water (98 - 103^{o}C) in 30 minutes, then dried in a condition of 103^{o}C.
- Testing sample of the density of 4-side compressed woodwas not applicable under the wood sample size according toTCVN as with the compression ratio of 36.31%, there was a difference between the coreand the surrounding surfaces of compressed wood section.
- Mechanical properties: Parallel compression strength to grain was tested according to standard TCVN 363:1970 (revised) and surface hardness of wood tested according to standard TCVN 369:1970 (revised) using an Universal Testing Mechanical MTS Qtest/25.

- Moisture content of sample when testing the mechanical properties is MC = 12% (controlled environmental condition: temperature T = 20^{o}C and relative moisture RH = 60% - using Climate Chamber Jeiotech TH-G180L).

2.4. Plan of experiment

Plan of multi-factorial experiment was conducted to figure out the relationship between some major physical properties of compressed wood and processing parameters.

- Relationship between targeted function Y and some parameters $x_1, x_2\ldots, x_n$ was described by a quadratic polynomial.

$$Y = b_0 + \sum_{i=1}^{k} b_1 x_1 + \sum_{i=1}^{k-1}\sum_{j=i+1}^{k} b_{ij} x_i x_j + \sum_{i=1}^{k} b_{ii} \quad (1)$$

In which:

$x_i = (X_i - X_{i0})/\Delta X_1$;

x_i - coded value of the parameters;

b_0 - free coefficient;

b_i- linear coefficient;

b_{ij}(i#j) - the repeating interactive coefficients;

b_{ij}- the quadratic efficient;

X_i - the real value of inputs;

X_{io} - the basic values of the parameters;

ΔX_1 - changing steps of the parameters;

k - the number of experiment parameters.

- The experiments conducted in experimental plan with shortened elements.

Total experiments:

$N = k(2^m + 2m + 1) = 9$ (2)

In which:

k - number of repetitions (as calcu. k = 3);

m - experimental variables (m = 2).

- The experimental level and changing steps in laboratory parameters were noted in table 1.

- Fixed factor: Round section of billets with diameter of 84mm, length of 40mm (no cracks, no other defects); 4-side compressed wood was processed in accordance with the wood softening mode by the microwave to soften *Styrax tonkinensis*core until the glassy state transformed into elastic state; Compression ratio was 36.31%; Compression speed was 10mm/min; after the end of the compression process, compressed wood was fixed in the mould and then was taken to dimensional stabilizing. Processing environment of size stabilizing at high temperature in a vacuum was P = 650mmHg.

- Changing factors:

+ Treatment temperature (τ): 170, 180, 190, 200 and 210^{o}C;

+ Treatment time (T): processing time was changed in 5 levels: 0.5, 2.5, 4.5, 6.5 and 8.5h.

- Output elements: Some basic mechanical and physics properties of 4-side compressed wood were: Recovery of set, weight loss, anti-swelling efficiency, density, parallel compression strength to grain and tangential section hardness.

- Calculated figures werethe average value of the experiment through 3 iterations.

2.5. Calculating the experimental value

a) The recovery of set

The recovery of set (RS) was calculated by the formula:

$$RS = \frac{T_r - T_c}{T_o - T_c} \times 100 \text{ , \%} \quad (3)$$

In which:

T_r – The thickness of dried wood after elastic test;

T_c – The thickness of dried wood after compressing;

T_o – The thickness of dried wood before compressing.

Testing results of the recovery of set of compressed wood with the parameters of heat treatment time and temperature were shown in table 1.

b) Weight loss

The weight loss of compressed wood (WL)was calculated by the formula:

$$WL = \frac{W_t - W_s}{W_t} \times 100 \ ,\% \qquad (4)$$

In which:

W_t – weight of dried sample before heat treated;

W_s – weight of sample after dimensional stabilizing.

Test result of the weight loss of compressed wood during dimensional stabilizing concerning time and temperature ofthe heat treatment were shown in table 1.

c)Anti-swelling efficiency

The anti-swelling efficiency (ASE) of the sample was calculated by:

$$ASE = \frac{S_u - S}{S_u} \times 100 \ , \% \qquad (5)$$

In which:

S - The dimensional change between the dried and saturated water states of treated samples;

S_u - The dimensional change between the dried and saturated water states of untreated samples;

The test results of anti-swelling efficiency in the process of dimensional stablizing according to time and temperature of the heat treatment were shown in table 1.

d) Density of compressed wood

Density (γ) of sample was calculated by the formula:

$$\gamma = \frac{m}{V} \qquad , g/cm^3 \qquad (6)$$

In which:

m - mass of wood at the MC = 12%;

V - volume of wood in the same condition.

The test results of density of compressed wood in the process of dimensional stablizing regarding time and temperature of the heat treatment were shown in table 1.

e) Compression strength parallel to grain and surface hardness

They were tested on MTS Qtest/25, wood in the MC = 12%; Compression strength parallel to grain was also called maximum crushing strength; Surface hardness was measured when load was perpen dicular to grainof tangential section (by the Brinell test).

III. RESULS AND DISCUSSION

3.1. Calculated results

The test results of characteristic parameters of compressed wood when changing temperature and time of the heat treatment were calculated, analyzed and summarized in table 1.

Table 1. The experimental levels and results of output parameters of compressed wood after heat treatment process for dimensional stability

N_0	τ (h)	T (^{0}C)	The average value of the indices					
			Recovery of Set Y_I	Weight Loss Y_{II}	ASE Y_{III}	Density Y_{IV}	Parallel Compres. Y_V	Surface Hardness Y_{VI}
1	6.5	200	3.86	3.55	41.82	0.54	49.52	72.05
2	2.5	200	11.68	1.05	22.12	0.55	52.14	75.86
3	6.5	180	25.62	0.98	32.84	0.55	52.68	76.64
4	2.5	180	55.35	0.42	19.63	0.56	55.47	79.79
5	8.5	190	9.54	1.58	40.25	0.54	49.55	72.09
6	0.5	190	70.85	0.28	9.64	0.56	58.51	83.49
7	4.5	210	4.60	2.80	37.20	0.54	49.42	71.90
8	4.5	170	45.84	0.78	10.24	0.56	57.64	82.46
9	4.5	190	19.72	0.95	20.32	0.55	53.26	77.49

3.2. Correlative equations and graphs

From the data in table 1, we could found the correlative equations between influenced factors (temperature, time) and typical technological properties of compressed wood, then create the correlation chart of influencing process. The details were shown as follows:

** The recovery of set of compressed wood*

- Code form of correlative equation:

$$Y_I = 25.191 - 16.103X_1 + 6.488X_1^2 - 16.59X_2 + 5.478X_1X_2 - 3.573X_2^2 \quad (7)$$

- Real form of correlative equation:

$$Y_{RS} = -542.831 - 71.947\tau_1 + 1.622\tau_1^2 + 9.97T_2 + 0.274\tau_1T_2 - 0.036T_2^2 \quad (8)$$

From the data in table 1 and the equation (8), it could represent the relationship between the time and temperature of heat treatment and the recovery of set in figure 1.

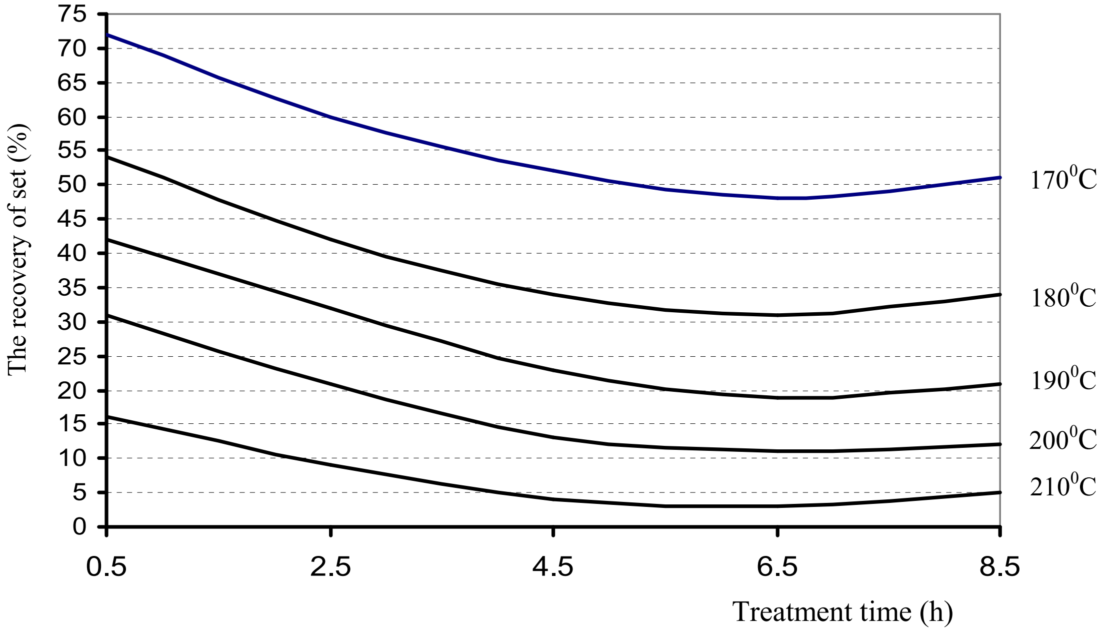

Figure 1. Relationship between the temperature and time of heat treatment and the recovery of set

The data in table 1, equation 3 and figure 1 showed that:

When the heat treatment time increased, the recovery of set of compressed wood increased. However, as time increased over 7 h, the recovery of setof compressed wood tended to slow down. As time increased over 8.5 h, the recovery of set of compressed wood tended to decrease. Similarly, when heat treatment temperature increased, the weight loss of compressed wood also increased and there was the signal of lightly redirecting when the temperature reached 200^{o}C.

**Weight loss of compressed wood*

- Code form of correlative equation:

$$Y_{II} = 0.95 + 0.666X_1 - 0.014X_1^2 + 0.812X_2 + 0.485X_1X_2 + 0.564X_2^2 \quad (9)$$

- Real form of correlative equation:

$$Y_{WL} = 187.08 - 4.00\tau_1 - 0.003\tau_1^2 - 2.057T_2 + 0.024\tau_1T_2 + 0.005T_2^2 \quad (10)$$

From the data in table 1 and correlative equation (10), we could express the relationship between the time and temperature of heat treatment and the degree of weight loss of compressed wood in figure 2.

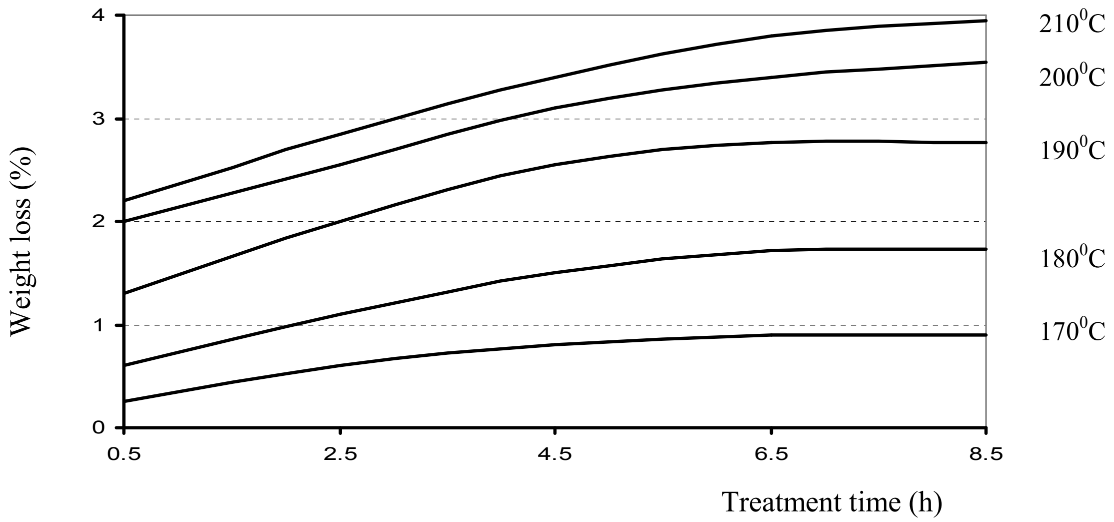

Figure 2. Relationship between temperature and time of heat treatment and the weight loss

We could see from the data in table 1, equation (10) and figure 2:

The level of weight loss of compressed wood increased with heat treatment time. But the processing time in the range of 6.5 to 8.5 hours, the level of weight loss of compressed wood was almost unchanged, even in the 190^{0}C heat treatment mode, it tended to decrease. Similarly, the increase in temperature led togrowth in the level of weight loss of compressed wood and that change was not significant when the temperature reached from 200^{o}C to 210^{o}C.

**The anti-swelling efficiency of compressed wood*

- Code form of correlative equation:

$$Y_{III} = 18.898 + 10.07X_1 + 4.997X_1^2 + 5.358X_2 + 1.622X_1X_2 + 4.174X_2^2 \quad (11)$$

- Real form of correlative equation:

$$Y_{ASE} = 1325.043 - 20.81\tau_1 + 1.249\tau_1^2 - 14.754T_2 + 0.081\tau_1T_2 + 0.042T_2^2 \quad (12)$$

From the data in table 1 and correlation equation (12), the relationship between time and temperature of heat treatment and anti-swelling efficiency of compressed wood is shown in figure 3.

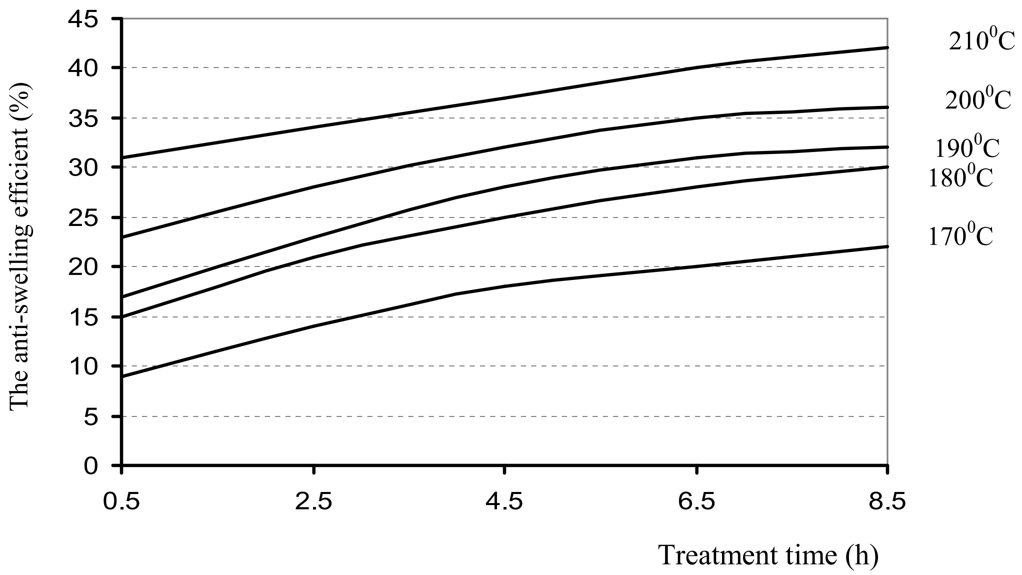

Figure 3. Relationship between time and temperature of heat treatment and ASE

From the data in table 1, equation (12) and figure 3, we could see:

When the heat treatment time increased, anti-swelling efficiency increased; Similarly, as the treatment temperature increased, the anti-swelling efficiency of compressed wood also increased. But as time exceeded 7.5h or temperature reached 205^{o}C or higher, the anti-swelling efficiency of compressed wood tended to slow down. And when the time increased to 8.5h or the temperature reached to 210^{o}C, the anti-swelling efficiency of compressed wood tended to decrease.

**Density*

- Code form of correlative equation:

$$Y_{IV} = 0.552 - 0.05X_1 - 0.002X_1^2 - 0.005X_2 - 0.002X_1X_2 - 0.001X_2^2 \quad (13)$$

- Real form of correlative equation:

$$Y_\gamma = 0.253 + 0.018\tau_1 - 0.005\tau_1^2 + 0.003T_2 - 0.001T_2^2 \quad (14)$$

From the data in table 1 and correlation equation (14), we could express: the relationship between the heat treatment time, temperature and the density of compressed wood according to the graph in figure 4.

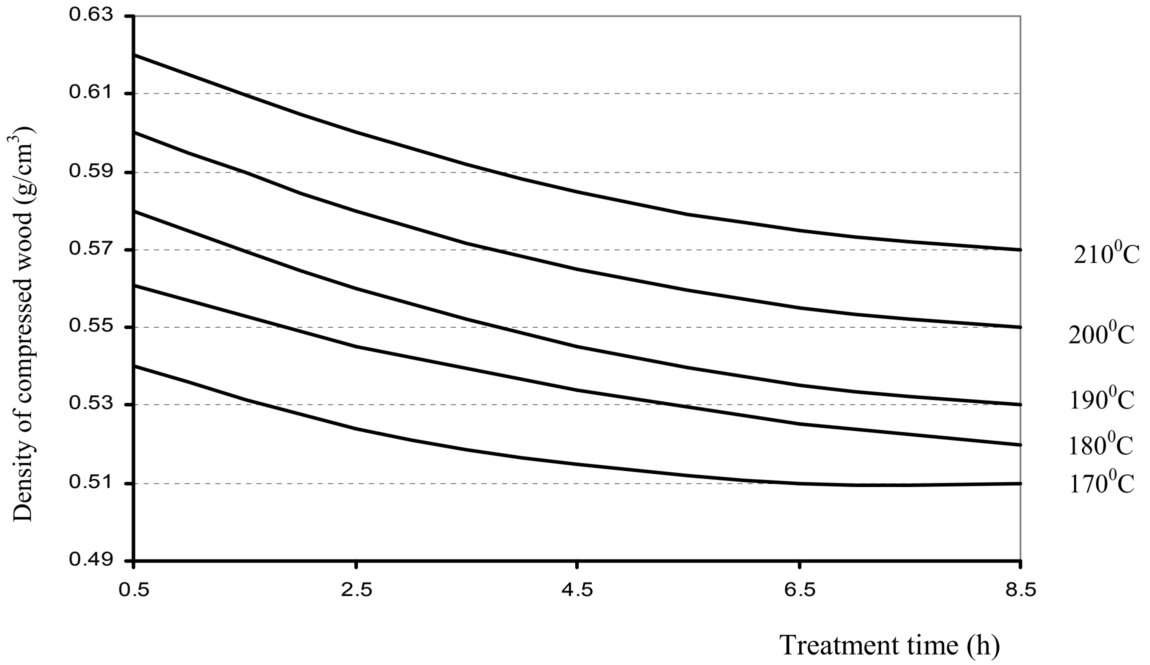

Figure 4. The relationship between temperature and time of heat treatment and wood density

We could see from the data in table 1, equation (14) and figure 4:

- Similar to weight loss of compressed wood during dimensional stabilizing: When the heat treatment time increased or heat treatment temperature increased, the volume of compressed wood decreased. Until the time exceeded 7.5h or temperature reached 203^{o}C or higher, the density of compressed wood tended to slow down. When the time increased to 8.5h or the temperature reached 210^{o}C, the volume of compressed wood changed insignificantly.

**The compressed strength parallel to grain*

- Code form of correlative equation:

$$Y_V = 53.892 - 2.3425X_1 - 0.322X_1^2 - 2.368X_2 + 0.042X_1X_2 - 0.658X_2^2 \quad (15)$$

- Real form of correlative equation:

$$Y_{PC} = 314.997 - 0.829\tau_1 - 0.08\tau_1^2 - 2{,}614T_2 + 0.002\tau_1T_2 + 0.006T_2^2 \quad (16)$$

From the data in table 1 and correlative equation (16), it could be expressed the relationship between the heat treatment time, temperature and the compressed strength parallel to grain of the compressed wood according to the graph in figure 5.

We could see from the data in table 1, equation (16) and figure 5:

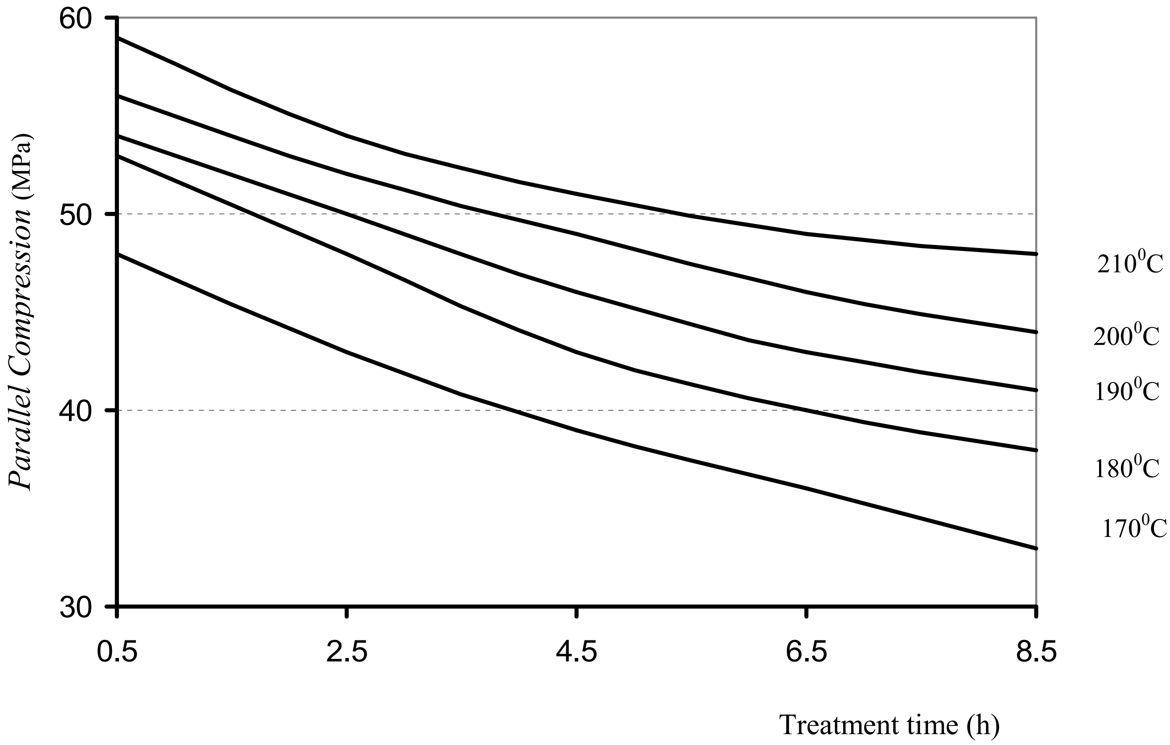

Figure 5. Relationship between time andtemperature of heat treatment and parallel compression

When the heat treatment time increased, the parallel compression strength of compressed wood decreased. However, when the time increased over 7.4h, the parallel compression strength tended to slow down. When the time increased to 8.5h, the parallel compression strength tended to increase slightly. Similarly, for the treatment temperature: the parallel compression strengthdecreased as temperature increased, rising more than 203^oC, the parallel compression strength along with the trend leveled off. And when the temperature increased to 210^oC, the parallel compression strength tended to decrease.

**Surface hardness*

- Code form of correlative equation:

$Y_{VI} = 78.077 - 2.9911X_1 - 0.578X_1^2 - 3.068X_2 - 0.165X_1X_2 - 0.987X_2^2$ (17)

- Real form of correlative equation:

$Y_{HT} = 189.497 + 1.289\tau_1 - 0.144\tau_1^2 + 3.28T_2 - 0.082\tau_1T_2 - 0.099T_2^2$ (18)

From the data in table 1 and correlative equation (18), it could be expressed the relationship between time and temperature of heat treatment and surface hardness of tangential section in figure 6.

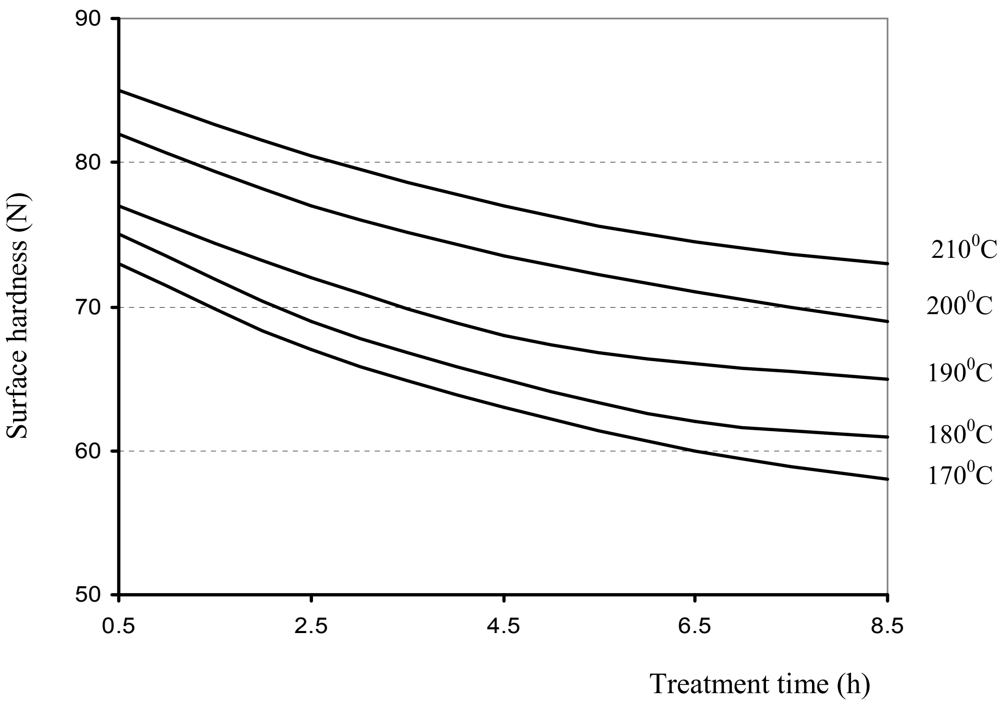

Figure 6. Relationship between time and temperature of heat treatment and surface hardness

From the data in table 1, equation (18) and figure 6, we could see:

When the heat treatment time increased, the surface hardness of compressed wood increased. However, as the time increased over 7.5h, the surface hardness of compressed wood tended to slow down. As the time increased to 8.5h, the surface hardness of compressed wood tended to decrease. When the treatment temperature increased, the surface hardness of compressed wood increased. However, when the temperature rose up to 203^{o}C, the surface hardness of the compressed wood tended to slow down. When the temperature increased to 210^{o}C, the surface hardness of compressed wood tended to decrease.

c) Solving the optimal task when researching on compressed wood's dimensional stabilizing

The purpose of this task was to figure out the heat treatment time {τ(h)}, treatment temperature {T (^{o}C)} in order to produce a type of compressed wood which had good quality and high treatment efficiency.

The correlative equations between affecting factors (treatment temperature and time) to some basic characteristics of compressed wood were founded as: (8), (10), (12) , (14), (16) and (18).

The multi-objective was solved by the method of exchanging the sub value (initiated by Prof. Haimes) to achieve the most suitable heat treatment mode;

Solving optimal task with boundary condition of furniture production materials having physical properties mainly in MC = 12% was shown as follows:

- Density: (0.55 – 0.75) g/cm^3;
- Compressed parallel to grain: (40 – 50) MPa;
- Hardness of tangential section: (50 – 70) N;
- Recovery of set: (1.5 – 4.5) %;
- Anti-swelling efficiency: (35 – 45) %.

The results were: τ = 4.527h, T =183.76^{o}C.

In fact manufacturers can choose: τ = 4.5h, T =185^{0}C.

3.3. Discussion

In the process of dimensional stabilizing of compressed wood with high temperature, prolonged time, some typical physical properties of compressed wood increased, but some mechanical properties decreased. Particularly:

- When the heat treatment time increased, the recovery of set of wood decreased and anti-swelling efficiency increased. That meant the level of dimensional stability increased with the treatment time. Those changes were reflected most clearly in the period from 0.5 - 4.5h. However, when the treatment time exceeded 7.0h, the weight loss of compressed wood tended to halt. The compressed strength decreased with maximum speed at the beginning of the process (from 0.5 - 2.5h), after that, this change was unclear and almost unchanged, especially when the treatment time was from 6.5 - 8.5h.
- When the heat treatment time was extended from 0.5 - 8.5 hours in vacuum condition with the temperature of 210^{o}C, the surface hardness on tangential section of 4-side compressed wood decreased inversely with the treatment time. However, the reduction level of strength of compressed wood was not greater than untreated wood, and the final value of the surface hardness and compressed strength parallel to grain of compressed wood were still higher than the untreated wood.

The cause of creating an effectiveness increase in some physical properties were the crystallization of cellulose molecules in the amorphous regions of the fiber as a result of high temperature; The high thermal treatment reduced hygroscopicity and resized the wood due to creating horizontal links or muzzling micro-capillary on the cell wall, reducing the water absorption ability of cellulose, hemicellulose and lignin that nature of the problem was to reduce the OH^- group in the component.

From the experimental and calculated results, we had some comments on compressed wood at moisture content of 12%, shape transformed compression with ratio of 36.31% as follows:

- When compressing wood with ratio of 36.31%, wood density and mechanical properties increased.
- When extending the treatment time, the recovery of set decreased and the dimensional stability increased.
- The optimal heat treatment parameters to achieve the compressed wood dimensional stability and some related properties was: 185^{o}C in vacuum condition for 4.5h. However, this proposed parameters did not mention other special requirements of the products.

When comparing the efficiency of the dimensional stabilizing process of compressed *Styrax tonkinensis*by heat treatment method with the research results of W. Dwianto, M. Inoue et al., (2001) about permanent fixation of compressive deformation of Albizia wood by heat treatment, with the same mode, the recovery of set of *Styrax tonkinensis*was higher than that of Albizia. In a research of W. Dwianto, T. Morooka et al., (2001) on stress relaxation of Sugi wood in radial compression under high temperature steam, we could realize that the efficiency of dimensional stability with high temperature steam was significant higher than this with only temperature.

IV. CONCLUSION

The temperature and time of heat treatment to stabilize the dimension significantly influenced the typical properties of compressed wood from *Styrax tonkinensis* wood. In the *Styrax tonkinensis* processing, with compression ratio of 36.31% in vacuum condition 650mmHg, when temperature rose up and the heat treatment time increased: i) The density of compressed wood changed but not significantly; ii) The dimensional stability increased over treatment time and temperature (set recovery of compressed wood decreased and anti-swelling efficiency increased); iii) Some mechanical properties of compressed wood decreased, it had redirect sign and halted when the temperature reached 200^{o}C, the treatment time was 7.0h. Specific changes were:

- When the heat treatment time increased, the recovery of set of compressed wood increased, it tended to level off and decrease when the time exceeded 7.0h and 8.5h respectively.

- When the heat treatment time increaseed, anti-swelling efficiency of compressed wood increased; Similarly, the treatment temperature increased, this efficiency of also increased. But as time exceeded 7.5h and temperature was higher than 205^{o}C, the anti-swelling efficiency tended to level off and decrease as time and temperature reached 8.5h and 210^{o}C accordingly.

- Typical mechanical properties of compressed wood (compressed strength parallel to grain and surface hardness) decreased as the heat treatment time increased, if it was treated in more than 7.5h, the compressed wood's strength would tend to level off and decrease when the time increased to 8.5h. This strength decreased as temperature increased, exceeding 203^{o}C, this strength tended to level off and continue decreasing when the temperature reached 210^{o}C.

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SỰ ẢNH HƯỞNG CỦA NHIỆT ĐỘ VÀ THỜI GIAN KHI XỬ LÝ ỔN ĐỊNH KÍCH THƯỚC ĐẾN TÍNH CHẤT CỦA GỖ NÉN CHỈNH HÌNH

Nguyễn Minh Hùng

Trường Đại học Lâm nghiệp

TÓM TẮT

Trong công nghệ sản xuất gỗ nén thì xử lý nhiệt ổn định kích thước gỗ nén giữ vai trò quan trọng vì nó làm giảm ứng lực dư trong gỗ sau khi nén chỉnh hình. Nghiên cứu này đề cập tới mức độ ảnh hưởng của nhiệt độ (160,170, 180, 190, 200, 210^{o}C) và thời gian (0,5, 2,5, 4,5, 6,5, 8,5 giờ) xử lý nhiệt ổn định kích thước gỗ nén làm từ gỗ Bồ đề *(Styrax tonkinensis)* trong điều kiện chân không 650mmHg. Kết quả chỉ ra rằng: i) Khi thời gian xử lý nhiệt tăng lên thì mức độ đàn hồi trở lại gỗ nén của gỗ nén giảm xuống và hệ số chống trương nở tăng lên, điều đó có nghĩa là độ ổn định kích thước tăng dần theo thời gian xử lý. Sự thay đổi đó thể hiện rõ rệt nhất trong khoảng thời gian từ 0,5 – 4,5 giờ. Tuy nhiên, khi thời gian tăng quá 7 giờ thì mức độ tổn hao khối lượng gỗ nén có xu thế chững lại. Đối với thông số nhiệt độ, khi tăng nhiệt độ xử lý thì độ ổn định kích thước tăng dần theo và nó có dấu hiệu chuyển hướng nhẹ đi và chững lại khi nhiệt độ đến khoảng 200^{o}C;ii) Trong quá trình xử lý ổn định kích thước gỗ nén bằng nhiệt độ cao làm cho khối lượng thể tích của gỗ nén giảm nhưng giảm không đáng kể và một số tính chất cơ học của gỗ nén cũng giảm theo nhưng vẫn cao hơn gỗ nguyên liệu (khi chưa nén). Cụ thể là: Ứng suất ép dọc giảm với tốc độ mạnh nhất ở thời gian đầu của quá trình xử lý (từ 0,5 – 2,5 giờ), sau đó sự tác động của nhiệt độ không ảnh hưởng nhiều, nhất là từ 6,5 – 8,5 giờ thì gần như không đổi; Khi kéo dài thời gian xử lý nhiệt để ổn định kích thước từ 0,5 – 8,5 giờ trong điều kiện môi trường chân không với nhiệt độ 210^{o}C thì độ cứng tĩnh trên mặt cắt tiếp tuyến (thực chất là mặt ngoài) của gỗ nén 4 mặt lại giảm nghịch biến với thời gian xử lý.

Keywords: Bồ đề, chỉnh hình, độ chống trương nở, gỗ nén, ổn định kích thước, *Styrax tonkinensis*.

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