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RESEARCH ARTICLE

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Heat-transfer process during hot-pressing of flakeboard

Abstract Hot-pressing is the main process in flakeboard manufacture. Studies in this field also emphasize the effect on the heat-transfer process of the following factors: hot-pressing temperature, original moisture content (MC), target thickness and target density. In this experiment, dynamic data of changes in temperature in mats can be logged through temperature transducers and a computer data log system. The results of the experiment indicate that the core temperature-time curve can be divided into three stages: a stage of a rapidly rising temperature, a stage of moisture vaporizing and a stage of a slowly increasing temperature. If the hot-pressing temperature or the original MC increases during the first stage, the temperature will increase at an accelerated rate. This rate of acceleration in thin or low-density boards is very high. During the second stage, increasing the hot-pressing temperature or decreasing the original MC can shorten the time used to vaporize moisture. In thin or low-density board, this time period is short. In the third stage the original MC does not affect the rate of temperature increase, while the effect of the other factors is the same as that at the first stage. Given different conditions, vaporization temperature in the mat changes.

Keywords flakeboard, hot-pressing, heat-transfer, vaporization temperature

1 Introduction

Hot-pressing is the critical process in flakeboard manufacture. It will not only decide the quality of products, but also will affect the consumption of energy and costs (Siau,1983; Kamke and Casey, 1988). Hata et al. (1989) have measured the temperature of the core of the mat in hot-pressing using thermocouples and came to the conclusion that the temperature of the core was in direct proportion to the hot-pressing temperature and inversely proportional to the square of the thickness of the mat. Liu et al. (1995) have investigated factors affecting the heat-transfer process during hot-pressing of particleboard. They concluded that some methods can shorten the time of rising temperatures, reduce temperature differences between surface and core and improve the shape of the temperature distribution curve in a section, such as decreasing the density or the thickness of the mat, increasing the hot-pressing temperature or the original MC or spraying water on the surface. In past investigations, researchers first obtained the values of the thermocouple current and then converted these to values of temperature by calculation (Johnson et al., 1993; Jing et al., 1999; Xu and Hua, 2002; Xie et al., 2003). This method is not suitable for real time temperature measurements and the measurement errors are large. Some people take it for granted that the vaporization temperature is 100˚C, so that past studies mainly emphasized processes where the temperatures were below 100˚C (Liu and Cai, 1992; Jing et al., 1999; Xu and Hua, 2002; Xie et al., 2003; Zombori et al., 2003). In our experiment, both thermal resistance and a computer data log system were adopted to obtain dynamic data of temperature changes of the core until the temperature reached 160˚C.

2 Materials and methods

2.1 Experimental materials and equipment

The raw material was poplar (*Populus tomentosa*), one of the fast growing species in China. Flakes of 35–45 mm long, 10–25 mm wide and 0.3–0.5 mm thick were prepared in the laboratory of Beijing Forestry University.

The equipment used consisted of a slicer, a thermoelectric blower oven, an infrared moisture content meter, a laboratory press, a mat-forming box, temperature transduc-

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ers (350 mm in length, 2.5 mm in diameter) and a computer data log system.

2.2 Methods

This experiment concentrated on testing temperature changes of the core, which is the last zone where resin is cured. The process of adding resin was omitted. Different kinds and amounts of resin will affect the heat-transfer of the mat differently. The amount of resin added to flakeboard is smaller than that for particleboard. In this study, the effect of resin was omitted.

2.2.1 Real time temperature measurements

In this experiment, both temperature transducers and the computer data log system were adopted to test the real time temperature changes of the core. Temperature transducers are thermal resistance meters made of Pt100, with a scale from 0 to 400℃ and measurement precision of 0.1℃. The computer data log system was composed of a RMA411 outlying block for testing thermal resistance, a RM4050 block (both produced by the Zhong Tai Co.) and a computer. The RMA411 outlying block can convert data from thermal resistance to temperature values with a measurement precision of 0.5℃. Figure 1 is a sketch of the temperature measurements.

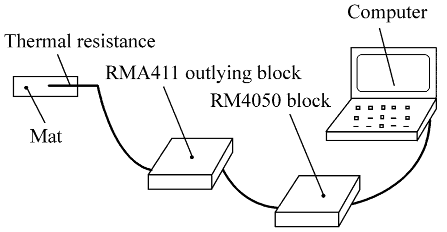

Fig. 1 Sketch of temperature measurement system

Temperature transducers were inserted in the center of the mat. The computer data log system sampled data every 5 s until the temperature of the core reached 160˚C.

2.2.2 Experimental layout

The design of the experiment is presented in Table 1.

3 Results and discussion

The core temperature-time curve can be divided into three stages (Fig. 2). Both the first stage and the third stage are stages of rising temperature, showing aperiodic and unsteady heat conduction. In the first stage, the curve shows a steeply rising slope. In the second stage, the core reached vaporization temperature, a five-minute period during which the temperature did not change, but its enthalpy changed and water changed to vapor. During the third stage, the period of vaporizing ended and the slope increased again. Development and observation will be discussed for each stage.

Table 1 Layout of the experiment

No.	Hot-pressing temperature/℃	Original MC /%	Target thickness /mm	Target density /(g • cm^{-3})
1	160	8	14	0.7
2	190	8	14	0.7
3	205	8	14	0.7
4	175	8	14	0.7
5	175	8	10	0.7
6	175	8	20	0.7
7	175	8	14	0.5
8	175	8	14	0.9
9	175	15.5	14	0.7
10	175	22	14	0.7

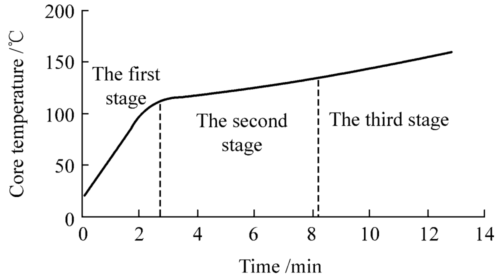

Fig. 2 Core temperature-time curve during hot-pressing of flakeboard. Hot-pressing temperature: 175˚C; original MC: 14%; target thickness: 14 mm; target density: 0.7 g/cm^3.

3.1 The first stage (a stage of rapidly rising temperatures)

With the plates closed, the temperature of the surface flakes increased quickly, while the temperature of the core flakes remained almost unchanged. A temperature gradient between surfaces and the core appeared and decreased with time. Heat transferred from the surfaces to the core by heat conduction and heat convection. Because of the high temperature of the surfaces, its moisture vaporized and gas pressure appeared in the surface layers. A pressure gradient between the surfaces and the core formed, which caused water (or water vapor) to diffuse from the surfaces to the core.

3.1.1 Effect of increasing hot-pressing temperature on rate of core temperature increase

Figure 3 indicates that in the first stage, the rate of increase in the core temperature accelerated as the hot-pressing temperature increased. The reason is that large temperature gradations can accelerate the rate of heat-transfer. The higher the hot-pressing temperature, the sooner the core reaches the curing temperature of resin.

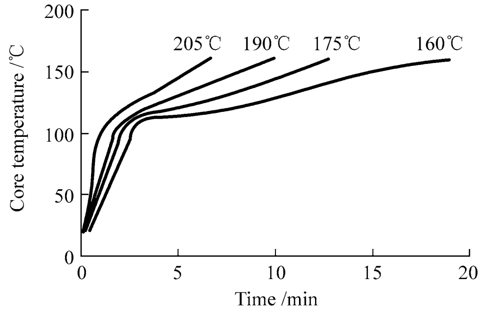

Fig. 3 Effect of hot-pressing temperatures on core temperature

3.1.2 *Effect of increasing MC on rate of core temperature increase*

Figure 4 shows that during the first stage, the rate of increase in the core temperature accelerated as the original MC increased. When the original MC was more than 8%, the rate of the core temperature accelerated. Thermal diffusivity of a mat with a high original MC is high, so that heat is conducted quickly.

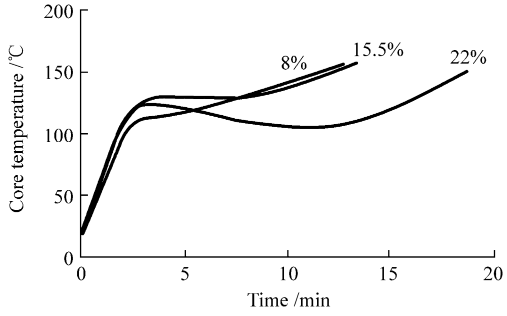

Fig. 4 Effect of original MC on core temperature

3.1.3 *Effect of target thickness on rate of core temperature increase*

Figure 5 indicates that the rate of increase of the core temperature in a thin mat was high. The 10 mm thick mat conducted heat quickly and the temperature reached 100°C almost instantly. The amount of heat supplied to these mats was equal for a given time period. If target thickness of the mat was small, thermal capacity of the mat was small and a greater amount of heat reached the core during the same time.

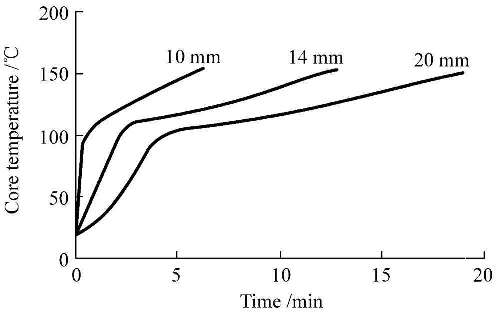

Fig. 5 Effect of target thickness on core temperature

3.1.4 *Effect of target density on the rate of core temperature increase*

Figure 6 shows that the rate of increase in the core temperature of a low target density mat was high. There are two reasons. One reason is that its thermal diffusivity is large. The other reason is that its penetrability is better and the resistance to vaporize moisture smaller than those of the other, higher density mats. Low-density mats conduct heat quickly.

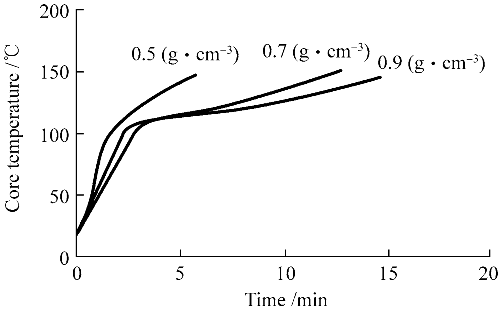

Fig. 6 Effect of target density on core temperature

3.2 The second stage (a stage of moisture vaporizing)

When the core temperature reached local vaporization temperature, heat was used as latent heat to convert moisture into vapor. Temporarily, the core temperature did not change, while the gas pressure of the core increased. The vaporization temperature of the core increased with increasing gas pressure. When this happened, some heat was used to increase the core temperature again. Once the core reached a new vaporization temperature, water began to be converted to vapor and the temperature again did not change. Therefore, although the core temperature changed a little, we can assume that it kept approximately constant during the second stage.

3.2.1 *Effect of hot-pressing temperature on vaporization temperature and time of moisture vaporization*

When the hot-pressing temperatures were 205, 190, 175 and 160˚C and the other three conditions remained the same (MC: 8%, target thickness: 14 mm, target density: 0.7 g/cm^3), core vaporization temperatures in mats were 120, 118, 116 and 113˚C, respectively (Fig. 3). Vaporization temperatures of mats with different hot-pressing temperatures vary little, because penetrability and resistance to vaporize water are the same in the mats under the same three conditions. However, the vaporization temperature in the mat with the highest hot-pressing temperature was little higher than in other mats, because vaporization in the mat was relatively strong and the gas pressure slightly higher.

The stage of vaporization was clearly visible in the mat with a hot-pressing temperature of 160˚C, while the mat with a hot-pressing temperature of 205˚C entered the next stage without an obvious vaporization stage (Fig. 3). The time for moisture vaporization decreased with an increase of the hot-pressing temperature. The reason is that in a given time period, heat supplied to the core is more in the mat with the highest hot-pressing temperature than in other mats, which can vaporize more moisture.

3.2.2 *Effect of MC on core vaporization temperature and time of moisture vaporization*

Vaporization temperatures of the mats with original MC of 15.5% and 22.0% were very close, about 125˚C, and that of the mats with original MC of 8% was 115˚C (Fig. 4). Resistance to vaporize water was very large in the mat with the higher original MC and the vaporization temperature was higher than in other mats. Time for vaporization increased with an increase in original MC. When the same amount of heat in a given time period was supplied to mats, a mat with more moisture required a longer time for vaporization.

3.2.3 *Effect of target thickness on core vaporization temperature and time of moisture vaporization*

Thick mats have low vaporization temperatures (Fig. 5). When other conditions are the same, a thick mat needs more energy for vaporization because it contains more moisture than a thin mat. This low vaporization temperature may result from a decrease in vapor pressure when a limited amount of heat in a given time period was supplied to this mat. In addition, according to the density distribution in a vertical section, we know that the density of the core layer in a thick mat is low and the penetrability of the core layer is good. The resistance to vaporize moisture is small and the vaporization temperature low.

Vaporization in thick mats requires more time. There are two reasons. One reason is that a thick mat has more water and needs more energy for this additional water to vaporize. The other reason is that the amount of heat that can reach the core in a given time period is smaller in a thick mat than that in a thin mat. That is, moisture in the core of a thick mat has less heat for vaporization.

3.2.4 *Effect of target density on core vaporization temperature and time of moisture vaporization*

A mat with a high target density has a high vaporization temperature (Fig. 6). That is because the penetrability of a high-density mat is limited and the resistance to vaporize moisture is large.

Vaporization of moisture in high-density mats also requires more time (Fig. 6). That is also caused by the large resistance to vaporize moisture. With the increase of the resistance, vapor pressure increases and the vaporization temperature also rises. In order to reach this high vaporization temperature, the core in a high-density mat needs more time to receive enough energy.

From the analyses above, it can be seen that vaporization temperature of the core in a mat is not 100˚C, what we usually assume. Vaporization temperatures ranged from 110 to 125˚C in this experiment. It is closely related to the gas pressure in a mat.

3.3 The third stage (a stage of a slowly increasing temperature)

Effects of the three factors (hot-pressing temperature, target thickness and density) on the rate of increasing temperature in this stage were similar to those in the first stage (Figs. 3, 5 and 6). That is, the rate of increasing temperature accelerated with an increase in hot-pressing temperature, target thickness and target density. The major reason is that both of these two stages belong to aperiodic and unsteady heat conduction. Because the reasons for these effects in the third stage are the same as those in the first stage, we will not repeat them.

The only difference between the two stages was the effect of original MC. It is shown in Fig. 4 that, during the third stage, there were no differences in the rates of temperature increases in the three mats with different original MCs. That is, the rates were not affected by the original MC in the third stage. After the second stage of moisture vaporization, the MC of the mats with different original MCs declined to the same level (about 4%). Thermal diffusivities of the mats remained the same in the third stage. Because the thermal diffusivity of a mat changed with MC and was lower in the third stage than in the first stage, the rate of temperature increase in the third stage was smaller than that in the first stage in a mat.

4 Conclusions

Based on the results from this study, several conclusions were drawn and these are listed below:

1. In a hot-pressing process, the core temperature-time change can be divided into three stages: a stage of a rapidly rising temperature, a stage of moisture vaporizing (temperatures barely change) and a stage of a slowly increasing temperature.

2. During the stage of a rapidly rising temperature, the heat supplied to a mat is mainly used to increase the core temperature. The rate of temperature increase can accelerate with an increase in hot-pressing temperature or in original MC. The temperature of a low-density mat or a thin mat increases quickly.

3. At the moisture vaporizing stage, the heat supplied to a mat is mainly used for moisture vaporization and the temperature remains almost constant. Under different hot-pressing conditions, vaporization temperatures vary. Time for moisture vaporizing can be shortened by increasing the hot-pressing temperature or decreasing the original MC. A low-density mat or a thin mat can take less time to vaporize its moisture.

4. During the stage of a slowly increasing temperature, the heat supplied to a mat is mainly used to increasing the temperature, which is the same as the stage of a rapidly rising temperature. However, the rate of temperature increase is slower than that in the first stage. This results from the decrease in MC and thermal diffusivity. Except for the original MC that does not affect the rate of temperature increase, effects of the other three factors are similar to those of the first stage.

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