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Center temperature changes in hot pressing Douglas fir particle board

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CENTER TEMPERATURE CHANGES IN
HOT PRESSING DOUGLAS FIR PARTICLE BOARD

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TABLE OF CONTENTS

LIST OF FIGURES

CENTER TEMPERATURE CHANGES
IN HOT PRESSING DOUGLAS FIR PARTICLE BOARD

I. INTRODUCTION AND LITERATURE REVIEW

Hot pressing is a very important procedure in the manufacture of particle board. The condition of the mats during hot pressing have a demonstrated effect on the final characteristics of the boards. The pressing conditions are also important in the total production of a plant because they are the controlling factors which determine the length of pressing time. The economics of production requires that the heating cycle be as short as possible, but it has to be long enough to allow the resin to cure sufficiently for further handling. Usually the pressing time depends on how long it takes to heat the center of the board. For the sake of shortening this time without impairing the quality of the products, the behavior of internal temperature rise during the pressing cycle, with varying mat conditions, is very important information for the manufacturers.

According to Carlyle (1) "the vaporization of the moisture detracts from the amount of energy that is available for hardening of the resin and increases curing time." "A reduction of the mat moisture content and an increase of press temperature was found to reduce the production cycle." Strickler (2) concluded that the rate of initial heat penetration to the center of particle boards increases as the over-all moisture content of the particle board mat increases and as the surface moisture content of the particle board mat increases. Crawford (3) stated that one of the "plus effects" of high mat moisture content is faster heat transfer to 212 degrees Fahrenheit, and one of the plus effects of low mat moisture content is shorter press time. From Crawford's statements, it follows that the rapid heat transfer by the high moisture content is effective only during the initial temperature rise. Suchsland (4) recommends low moisture content of particles to shorten press time. The so called "steam shock" method, pressing boards with high surface moisture content is recommended in several literature references (1), (2), (4).

There are two references concerning the influence of press temperature on heat conduction; both of them recommend high press temperature (1), (4). Unfortunately, such a recommendation must be subject to qualifying limitations since "excessive temperatures may produce premature drying of the surfaces, excessive resin cure (resulting in brittle and flaky resin and a fragile surface), and scorching or burning of the surfaces." (1).

In connection with the influence of pressure, Strickler (2) has stated that the rate of temperature rise in flakeboards increases perceptibly with higher initial pressure, because higher pressures give more intimate contact between flakes and between individual wood fibers. By his own admission, however, by controlling the pressure, he sacrificed the control of thickness and density.

The work of Strickler (2) is the most detailed, but the author did not go beyond the initial rise in temperature. He did not go through the complete pressing period because the temperature curves were erratic after the initial temperature rise. This, he stated, occurred because thermocouple wires could not be placed in the exact center of the mat, and because the wood flakes in the mat could not distribute perfectly. Practically, the curing rate of resin is a function of the combination of time, temperature and pH. By properly adjusting these factors, most of the resins used in today's particle board manufacture can be cured in the range of the initial temperature rise stage which he investigated. However, in order to collect more complete information concerning the heat conduction phenomena in pressing particle board, it is still necessary to determine the behavior of temperature rise after the initial rise to advance our knowledge and understanding.

II. STUDY PLAN

A. Purpose

The purpose of this study was to determine how the temperature change at the center of a board is effected during hot pressing by moisture contents, thicknesses of the boards, specific gravity and platen temperatures. This study could provide manufacturers with information that could be used in regulating the hot pressing conditions so that pressing time could be shortened.

B. Experimental Methods

The effect of these different factors on center temperature change during pressing cycle was investigated by making boards with several variations of moisture content, board thickness, specific gravity and platen temperatures. When boards were hot pressed, a thermocouple was used to measure the temperature changes at the center of the board.

The effects of change in moisture content were studied in four tests in which the moisture content was seven percent, nine percent, eleven percent and nine percent over-all moisture content with an additional five percent added, equally divided, upon the two surfaces. The effects of change in board thickness were studied in three tests in which the board thickness was 0.75 inches, 0.5 inches and 0.25 inches. The effects of change in specific gravity were studied in three tests in which the specific gravity was 0.6, 0.8 and 1.0. The effects of change in platen temperature were studied in three tests in which the platen temperature was 360 degrees, 320 degrees and 280 degrees (the unit of temperature used in this study was degrees Fahrenheit). In each test only one of these four factors was changed, and the rest of them were fixed at a common level. The common level of moisture content was nine percent; the board thickness was 0.5 inches; the specific gravity was 0.6 and the platen temperature was 320 degrees.

In order to eliminate one of the problems encountered by Strickler (2), before the mat was made the material was first weighed into two equal parts. One part was spread evenly on the bottom of the mat, a thermocouple wire was then placed on the top of this half of the mat. To prevent the wires from moving up or down during pressing, they were twisted onto a thin sliver of wood. Next, the rest of the material was spread evenly on the top. By this technique, the deviation of wires from the center of boards was minimized. Before testing, the pyrometer-thermocouple apparatus was checked and adjusted with ice water (32 degrees) as a reference junction. During the pressing period, the temperatures at the center of boards were recorded at each one minute interval.

After the boards were tested, they were cut across the thermocouple joint. If the position of the joint deviated from the center of the cut section more than half of the diameter of the wire junction, the board and its data was discarded and the test was duplicated.

Each test was repeated five times. Using the average value of the five recorded temperature readings taken at one minute intervals, a temperature-time curve was plotted for each test. Analysis and comparisons were then made from the resulting curves.

C. Materials

Wood samples used in this study were Douglas fir machined flakes, which were supplied by the Pack River Lumber

Company, Sand Point, Idaho. The binder used was Casco Resin WW-22, a urea-formaldehyde resin made by the Borden Chemical Company.

III. RESULTS, ANALYSIS AND DISCUSSION

The results of this study are presented in the following discussions and in figures 1 through 7.

A. The Analysis of Curves in General

The temperature-time relationships plotted from the resulting data can be divided into three basic types of curves as follows:

1. The type I curve

A typical type I curve (see Figure 1) consists of the following stages: (a) Stage 1, the initial temperature rise stage, in which the temperature rises rapidly from room temperature to about the boiling point of water at the elevation of test (208 degrees); (b) Stage 2, the water vaporization stage, in which the temperature remains at a fairly constant level, slightly higher than the boiling point of water, for a period of time; (c) Stage 3, the secondary temperature rise stage, in which the temperature climbs up again with a steady slope; the angle of this slope is much smaller than that of the initial temperature rise slope; and (d) Stage 4, the final temperature rise stage, in which the rate of change of the curve gradually decreases as the temperature at the center of the board approaches the press platen temperature. There is no clear demarcation between stage 3 and stage 4.

2. The type II curve

The type II temperature-time curve also consists of four stages (see Figure 2). The difference between

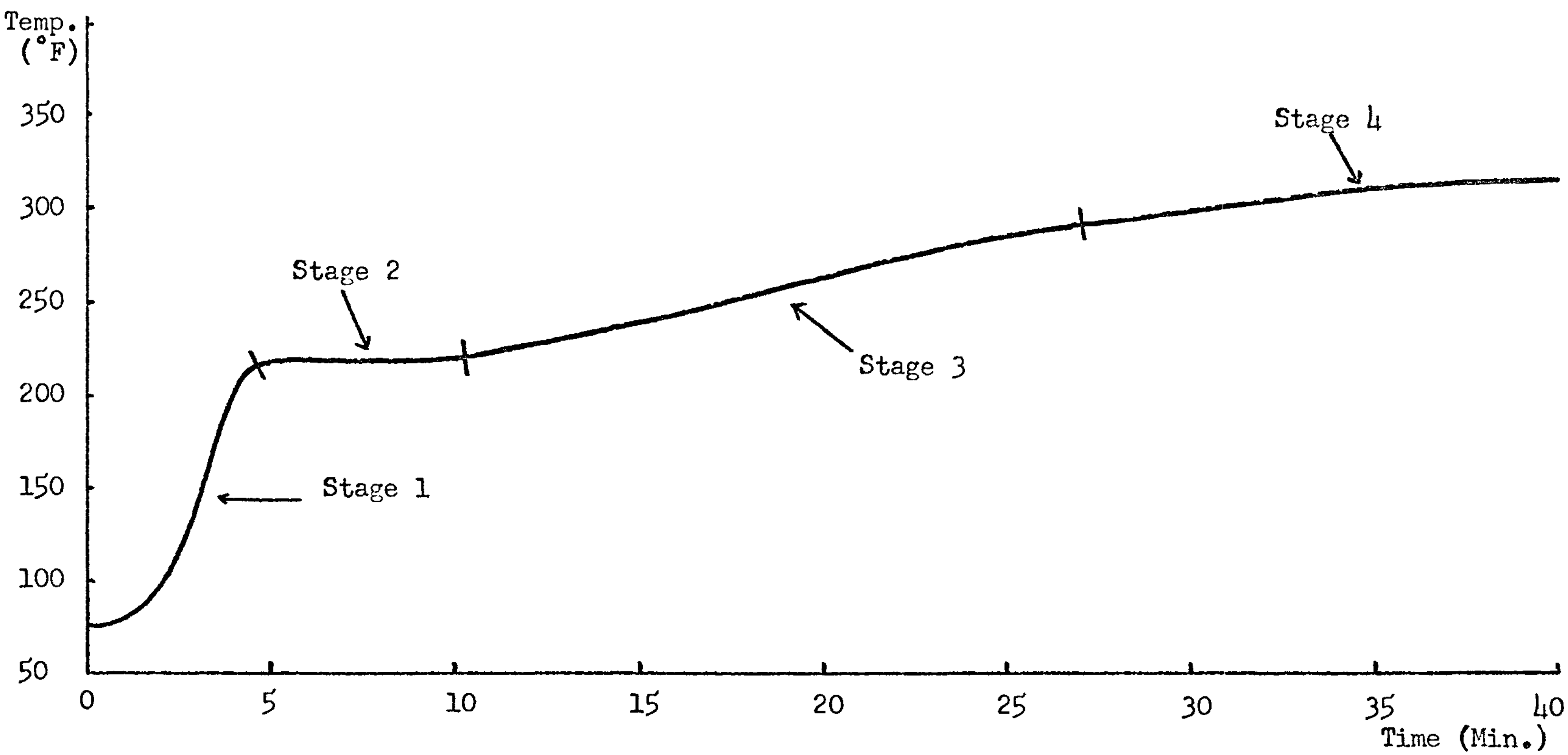

Figure 1. An example of type I curve

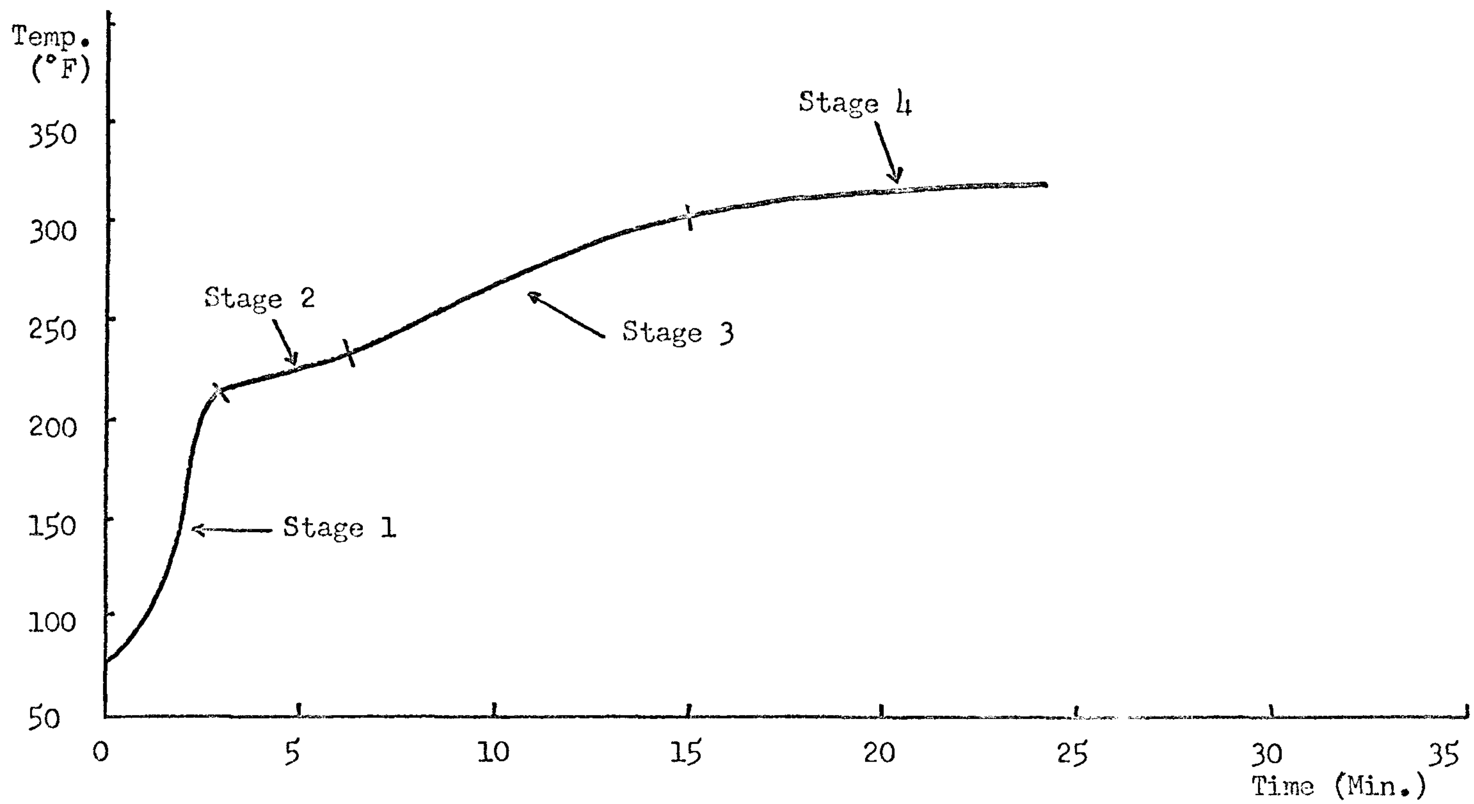

Figure 2. An example of type II curve

type I and type II is that there is no clear demarcation between stage 2 and stage 3 in the type II curves. The stage 2 in this type of curve does not remain constant at a given temperature, it rises very slowly. When the water in the boards is vaporized, the slope becomes steeper, and goes into stage 3.

3. The type III curve

The type III temperature-time curve does not have the previously described four stages (see Figure 3). Rather, the temperature continuously rises from room temperature to the platen temperature. The steepness of the slope of the curve decreases gradually as the temperature gradient drops.

In this study, most of the curves are of the type II category.

B. The Analysis of The Effects of Moisture Content

The following results were obtained from the tests in which the moisture content was changed:

1. In the entire temperature rise, the lower the moisture content of the mats the faster the speed of temperature rise at the center of boards.
2. High surface moisture content of mats has a beneficial effect on the initial temperature rise stage. In the latter part of the pressing period (from 215 degrees to the final temperature of 320 degrees), the favorable effect of the earlier temperature rise due to high surface moisture is lessened by the long period required for water vaporization.
3. There are no differences in the initial temperature rise stage resulting from the varying over-all moisture content.

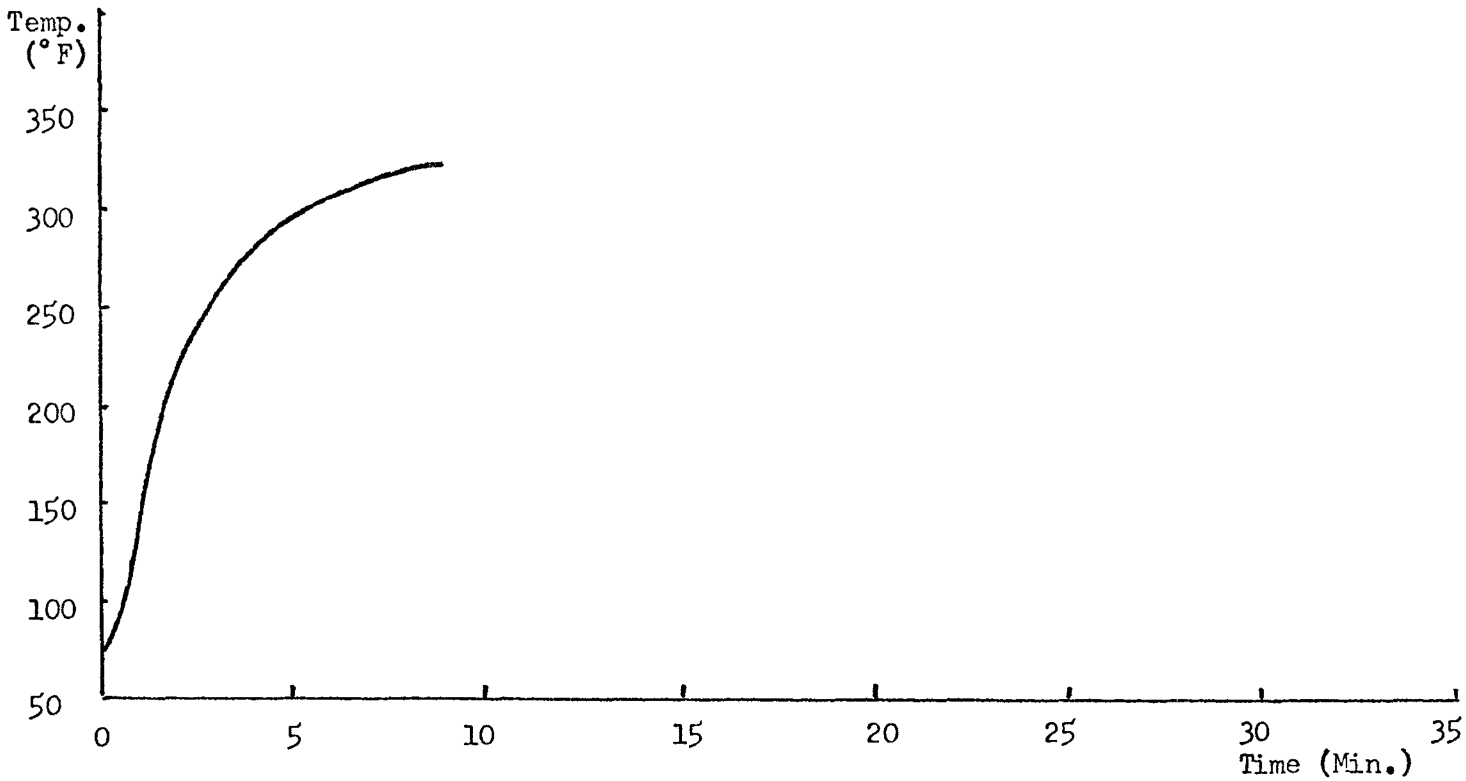

Figure 3. An example of type III curve

4. The effect caused by low moisture content of mats is effective in increasing the rate of temperature rise until stage 3 (about 290 degrees) is reached. If the pressing time continues into stage 4, the favorable effect is lost.

The illustrations of these results are shown in Figure 4 and described in the following discussions.

In Figure 4 curves 1A, 1B and 1D follow the same path in the initial temperature rise stage, while curve 1C rises much more rapidly than the others. This suggests that high surface moisture content can improve initial heat penetration. It would appear that high surface moisture can very quickly produce a large amount of water vapor on the board surfaces. In turn, heat energy is more rapidly carried into the center of the board by the water vapor diffusion across the pressure gradient formed.

When the temperature reaches the boiling point of water, the vaporization of water takes place. Figure 4 indicates that the smaller the percentage of moisture contained in the boards, the steeper the curve of stage 2, indicating an increase in the temperature rise. This is a logical consequence of the reduction in evaporative cooling.

In stage 3, the slopes of all the curves are nearly equal. It would appear that, because the influence of water is eliminated in this stage, all the boards are then under the same controlling conditions.

In Figure 4 it appears that the curve of low moisture content goes into stage 4 earlier than the high moisture content curves. The slopes of the four curves gradually flatten out, meet at approximately 312 degrees and continue to be the same up to the platen temperature of 320 degrees.

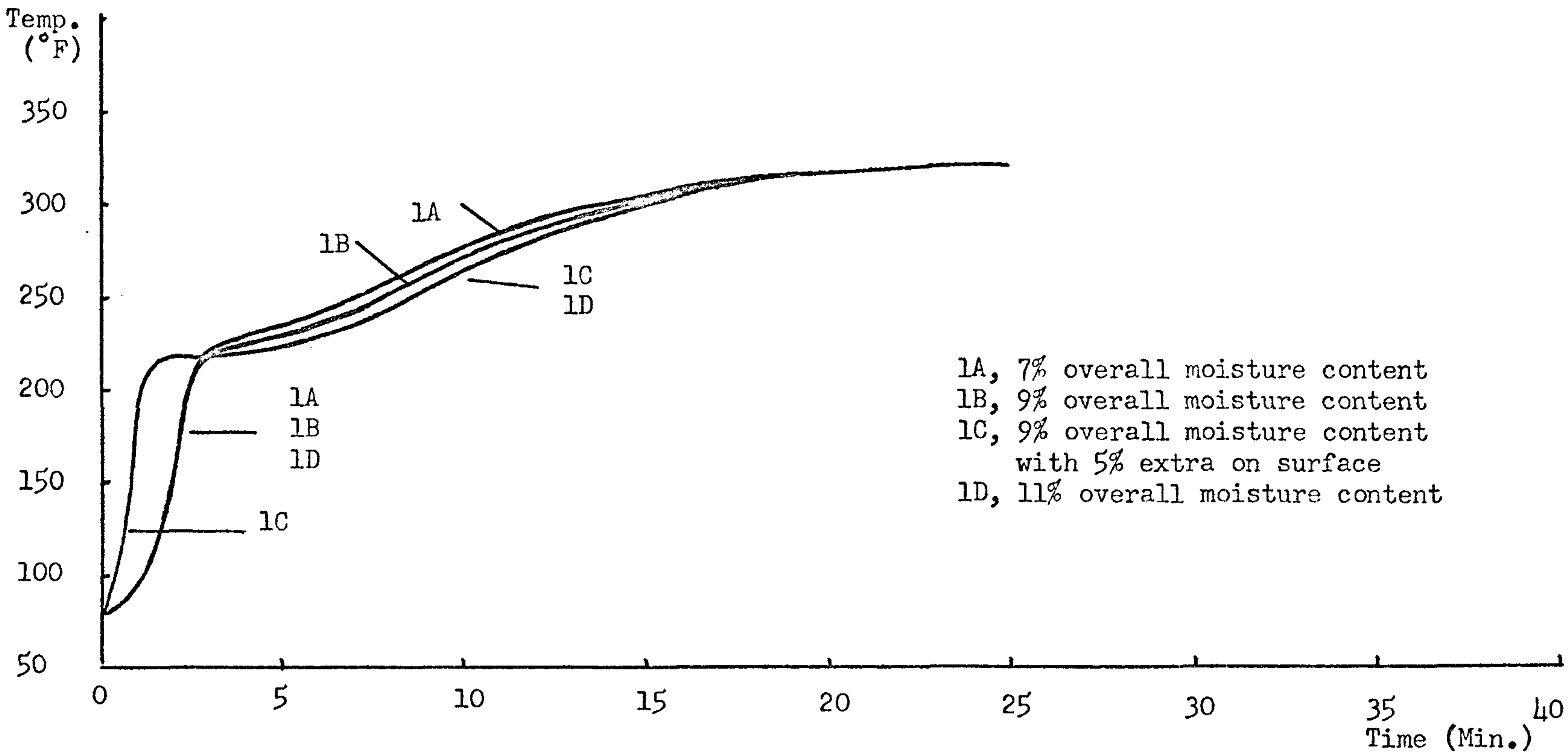

Figure 4. Rate of temperature change in the center of particle boards during hot pressing for four moisture content tests. The included information indicates the moisture content of each test. All the tests are at the following conditions:

thickness: 0.5 inch
specific gravity: 0.6
platen temperature: 320 °F

C. The Analysis of The Effects of Board Thickness

The following results were obtained from the tests in which the board thickness was changed:

1. Board thickness is a very important factor influencing the pressing time.
2. The total moisture plays a very important role in the effect of board thickness.
3. The effect of board thickness is much greater in the secondary temperature rise stage than in the initial temperature rise stage.

The illustrations of these results are shown in Figure 5 and described in the following discussions.

In Figure 5 curve 2C belongs to type III. The temperature at the center of the boards rises continuously. It does not have a water vaporization period. Curve 2B belongs to type II. It has a short and indistinct vaporization stage. Curve 2A belongs to type I. It has a long and very definite water vaporization stages. The reasons for the different water vaporization stages appearing in these three curves are thought to be as follows: (a) The thinner boards have less total moisture, even though the percentage moisture content is the same. Therefore it is easier for the water to be vaporized; and (b) It is easier for water vapor to escape from the thinner boards because of less mass resistance.

Figure 5 also shows that the time required for raising the temperature at the center of boards to a given level is not proportional to the thickness of boards. In the initial temperature rise stage, the time required for thicker boards does not differ from that required for the thinner boards as much as in the secondary temperature rise stage. This seems to be due to the effect of heated water vapor flowing to the center of the boards where the vapor pressure is lower. Beyond the initial temperature rise stage, the increase of

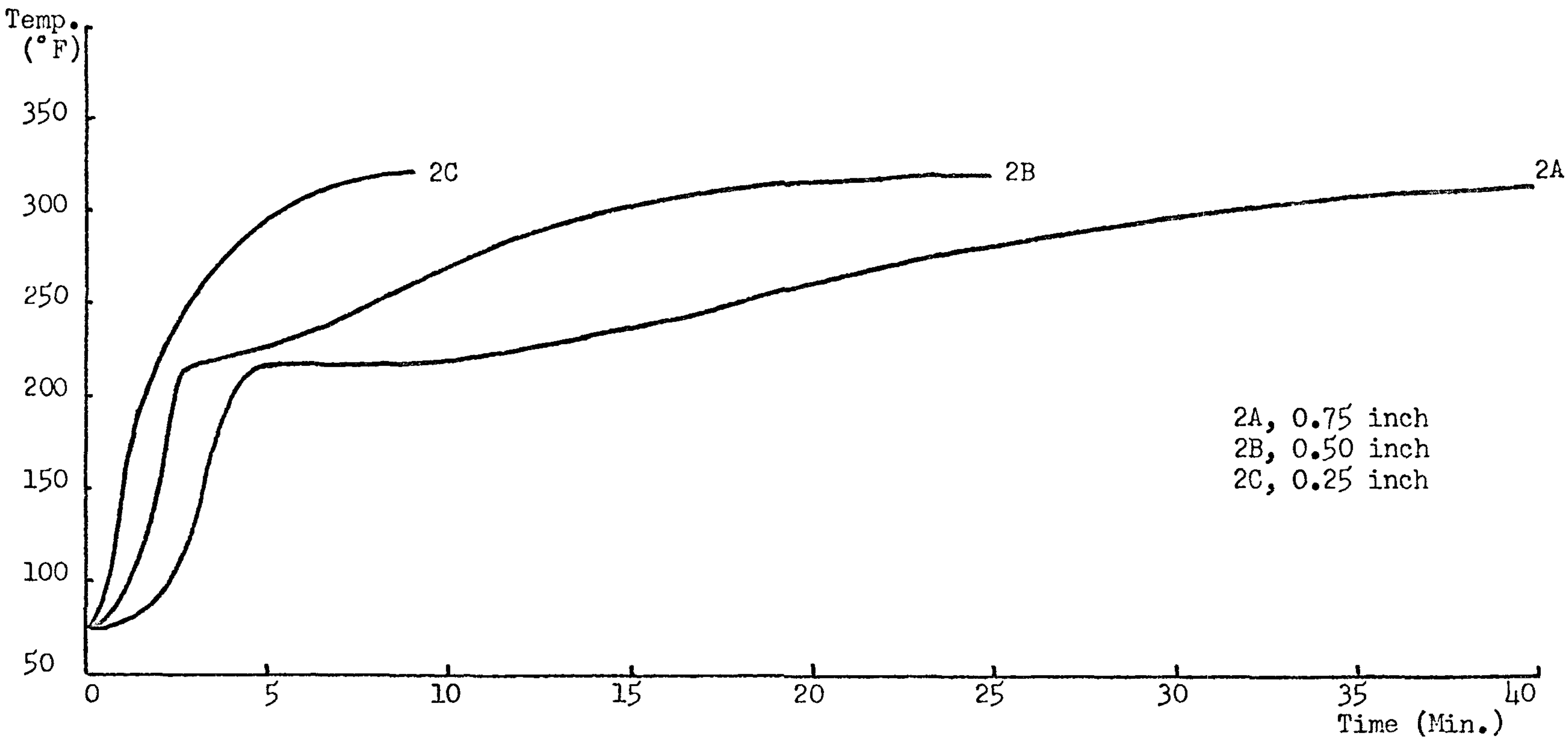

Figure 5. Rate of temperature change in the center of particle boards during hot pressing for three board thickness tests. The included information indicates the board thickness of each test. All the tests are at the following conditions:

moisture content:	9%
platen temperature:	320 °F
specific gravity:	0.6

board thickness has much effect on increasing pressing time. For example, temperature rise time from room temperature to 220 degrees takes 2 minutes for curve 2C, 3.6 minutes for curve 2B, and 5 minutes for curve 2A. The ratio of time required is 1 : 1.8 : 2.5. Temperature rise time from 220 degrees to 280 degrees takes 2 minutes for curve 2C, 8 minutes for curve 2B and 20 minutes for curve 2A. The ratio of time required is 1 : 4 : 10. The ratio of board thicknesses for these three curves is 1 : 2 : 3.

D. The Analysis of The Effects of Board Specific Gravity

The following results were obtained from the tests in which the board specific gravity was changed:

1. The initial temperature rise stage of the high density boards keeps on to a higher temperature than that of lower density boards.
2. The boards with lower specific gravities are better in terms of rapidity of initial heat penetration.
3. The temperature rise for the boards with high specific gravity is faster in over-all perspective than that for the boards with lower specific gravities.
4. Water vapor is trapped in the high density boards throughout the pressing period. If excessive, this may cause internal rupture or "blow" when the board is removed from platen pressure.
5. The total moisture plays a very important role in the effects of board specific gravity.

The illustrations of these results are shown in Figure 6 and described in the following discussions.

The behavior of temperature changes in the boards of different specific gravities is very complicated. Figure 6 shows that higher density boards expand the initial temperature rise stage to a higher degree. For the boards of 3A, the initial temperature rise stage continues to 215 degrees.

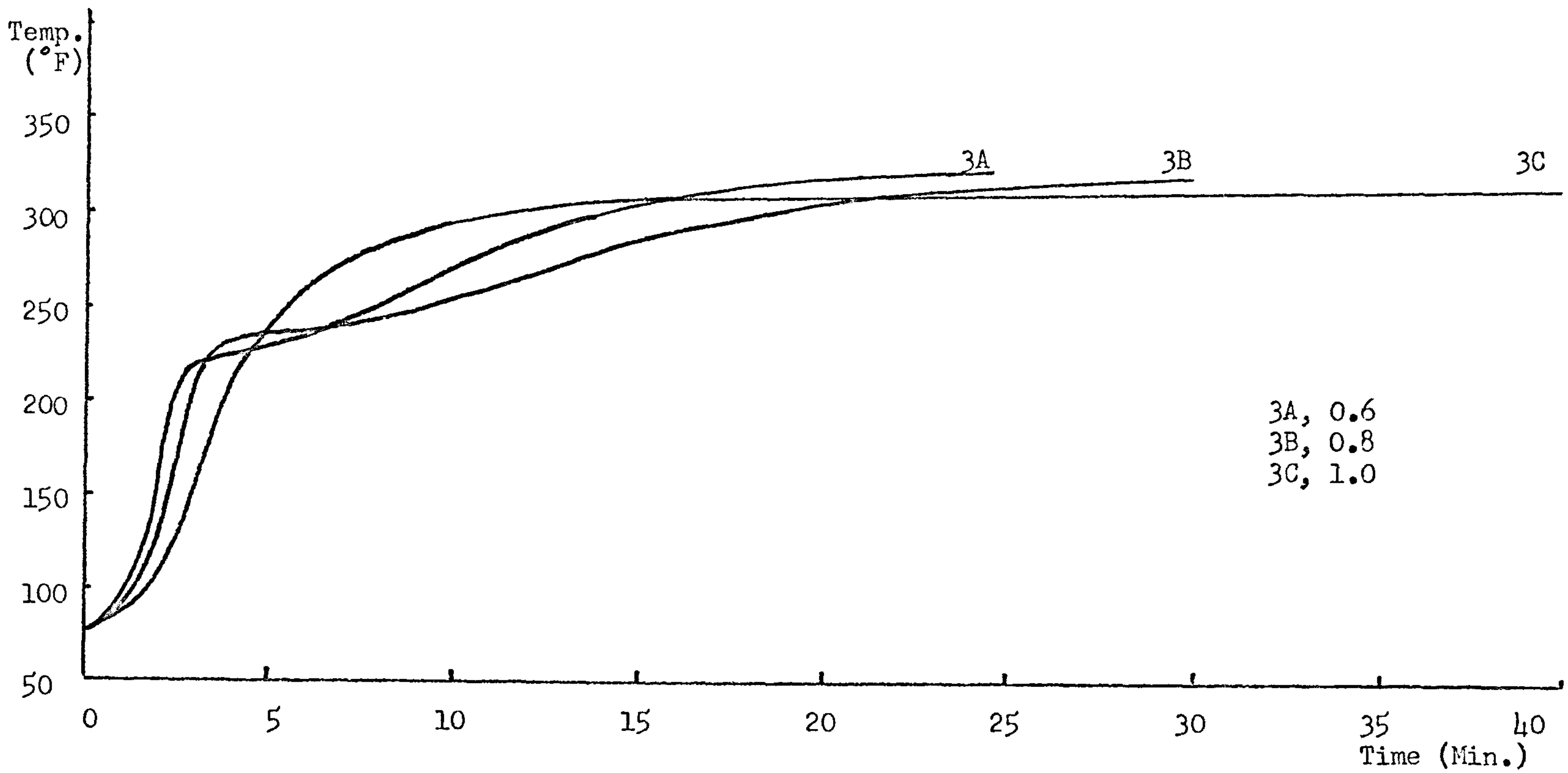

Figure 6. Rate of temperature change in the center of particle boards during hot pressing for three board specific gravity tests. The included information indicates the board specific gravity of each test. All the tests are at the following conditions:

moisture content: 9%
thickness: 0.5 inch
platen temperature: 320 °F

For the boards of 3B, the initial temperature rise stage continues until 230 degrees. For the boards of 3C, this stage continues to about 300 degrees. Figure 6 shows also that the higher density boards cause the curve to stay at the water vaporization stage longer, and also cause the slope of this stage to be more gentle. For the curve 3C, this stage continues for 38 minutes and, it is assumed, until it reaches the final temperature (320 degrees) it continues in the water vaporization stage. The evidence for this assumption is that when the boards of this group were removed from the platen pressure, the center of all of them separated explosively. This would indicate that water vapor was still trapped in the center of the boards, and it has built up a very high vapor pressure. These two tendencies would appear to be due to the following: (a) The high density boards contain more raw material than the low density boards, and therefore, contain more total moisture. This appears to be the reason why the water vaporization stage of the high density boards is longer; (b) The flakes in high density boards are under higher pressure than those in low density boards, and this higher pressure gives more intimate contact between flakes and between individual wood fibers within flakes. Therefore, it is difficult for water vapor to escape from the boards, and thus the vapor pressure builds up. This appears to answer the question concerning the temperature rise difference between low and high density boards at the end of the initial temperature rise stage. This might also explain why the water vaporization stage of the high density boards is longer than that of low density boards.

Figure 6 also shows the initial temperature rise of low density boards is faster than that of high density boards. This appears to be due to the more porous texture of the lower density boards which permit the water vapor formed at the board surfaces to flow to the center more easily. Figure 6 shows that the slope of the temperature rise of low density boards beyond the boiling point of water is also steeper than that of high density boards. Low density boards go into stage 2 earlier than the high density boards. Therefore the curve for low density boards is partly below the curve for high density boards. When all the curves go into stage 2, the curve for low density boards still surpasses the curve for high density boards.

E. The Analysis of The Effects of Platen Temperature

The following results were obtained from the tests in which the platen temperature was changed:

1. Increasing platen temperature can proportionally reduce the pressing time in stage one.
2. The effect of increased platen temperature decreases in proportion to the platen temperature increase after stage one has been passed.

The illustrations of these results are shown in Figure 7 and described in the following discussions.

Figure 7 shows that high platen temperatures can speed up the temperature rise both during the initial temperature rise stage and after the initial temperature rise stage. The effect of increased platen temperature in the initial temperature rise stage is constant. In other words, the same degree of temperature increase on platens can increase temperature rise with the same time interval. For example, curve 4C takes 3.5 minutes to reach 210 degrees. The 40 degrees increase on platen temperature can shorten the time for curve 4B to reach the same temperature to 2.8 minutes. Another 40 degrees increase in platen temperature can shorten the time for curve 4A to reach the same temperature to 2.1 minutes. The reduced time between the adjacent curves are all 0.7 minute. The

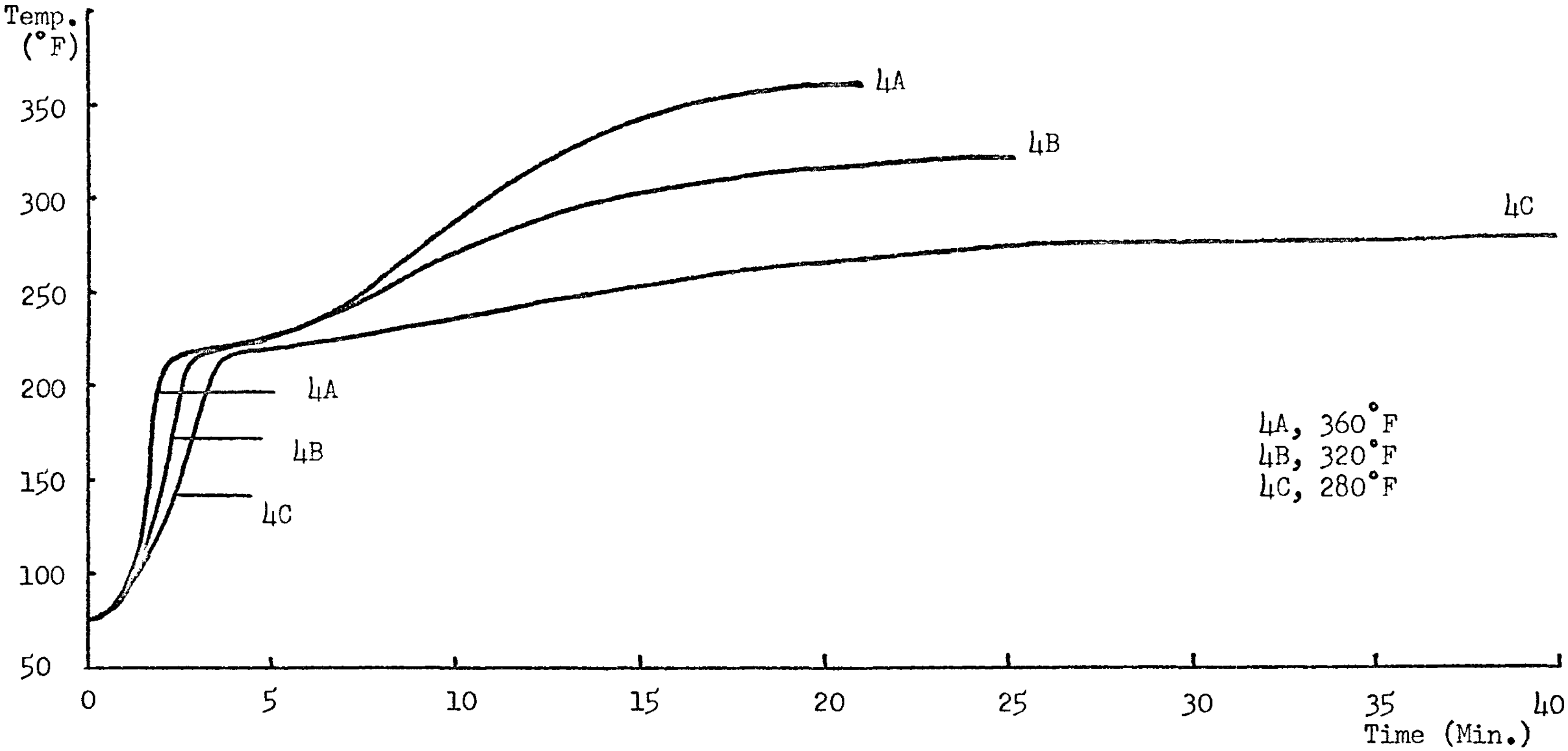

Figure 7. Rate of temperature change in the center of particle boards during hot pressing for three platen temperature tests. The included information indicates the platen temperature of each test. All the tests are at the following conditions:

moisture content:	9%
thickness:	0.5 inch
specific gravity:	0.6

effect of increased platen temperature beyond the initial temperature rise stage is not in constant proportion. For example, curve 4C takes 10 minutes to reach 250 degrees from 220 degrees. The 40 degrees increase in platen temperature shortened the time for curve 4B to ascend from 220 to 250 degrees to 5 minutes. Another 40 degrees increase on platen temperature shortened the time for curve 4A to ascend the same range (220 to 250 degrees) to 4.2 minutes. The reduced time between curve 4C and curve 4B is 5 minutes, but between curve 4B and 4A is only 0.8 minutes.

IV. SUMMARY OF CONCLUSIONS

A. The basic temperature-time curve is considered to be typically composed of four stages, the initial temperature rise stage, the water vaporization stage, the secondary temperature rise stage and the final temperature rise stage.

B. Moisture Content Effect on Center Temperature Change

1. In the initial temperature rise stage, only high moisture distribution on the surfaces of the mats showed an advantage in center temperature rise. There was no difference between other moisture contents. In Strickler's study (2) he concluded that the rate of initial heat penetration to the center of particle boards increases as the over-all moisture content of the particle board mat increases and as the surface moisture content of the particle board mat increases. The conclusion of this study disagrees with the first part of his statement but confirms the latter part of it. This difference may be due to the higher platen temperature used in this study. In this study 320 degrees Fahrenheit platen temperature was used, while in Strickler's study 290 degrees Fahrenheit platen temperature was used. The higher platen temperature used in this study caused the slope of initial temperature curves to rise more steeply than those reported by him. Possibly

it also caused the curves to coincide with each other, but there is no proof of this.

2. The high surface moisture content is advantageous for initial temperature rise only. In the entire testing period it does not have a good effect on speeding up the pressing time. In commercial production, most of resins are used with a platen temperature between 280 and 340 degrees Fahrenheit, but the pressing operation is stopped while still within the initial temperature rise stage. Therefore the "steam shock" method is effective as recommended in earlier literature references (1), (2), (4).
3. Other than in the "steam shock" method, the effect of moisture content appears mainly in the water vaporization stage (stage 2). The length of time in the water vaporization stage of the temperature-time curves depends mainly on the total moisture content of the mats. The more moisture contained, the more distinct this stage becomes and the longer it continues. In the tests of board thickness and specific gravity, because the total moisture content is changed when these other factors are varied, the water vaporization stage of the temperature-time curves is then influenced according to the total moisture content. Therefore total moisture content is an influencing factor when combined with board thickness or specific gravity when pressing operations go beyond the initial temperature rise stage.
4. In some earlier literature references (1), (3), (4) low moisture content is recommended to shorten "production cycle" or "pressing time". The results in this study agree with them only if these time periods go beyond the initial temperature rise stage. If the time period referred to is in the initial temperature rise stage, as stated previously, this study is in disagreement as only high surface moisture content was found to be of benefit in

reducing pressing time.

C. Board Thickness Effect on Center Temperature Change

1. The thickness of the board is a distinctly influencing factor in center temperature change.
2. The time required to raise the temperature at the center of a board a certain number of degrees is not proportional to the thickness of the boards. In the initial temperature rise stage, the thickness of the board has less effect on temperature rise than in the secondary temperature rise stage.

D. Specific Gravity Effect on Center Temperature Change

1. The specific gravity of the board is an effective influencing factor in center temperature change.
2. The boiling point of water is increased by the increase of confined pressure in high specific gravity board, and therefore the initial temperature rise is prolonged to a higher temperature.
3. The rate of temperature rise for low density boards is faster than that for high density boards, both in the initial temperature rise stage and the secondary temperature rise stage, due to their greater porosity and lower total moisture.
4. There is high vapor pressure built up in high density boards and more total water is present. This impedes the temperature rise during the latter part of the hot pressing period, and causes "blows" of the boards when removed from platen pressure.

E. Platen Temperature Effect on Center Temperature Change

Higher platen temperature can speed up the temperature rise both in the initial temperature rise stage and the secondary temperature rise stage. This conclusion confirms Carlyle's (1) and Suchsland's (4) statements, in which the high press temperature is recommended. This study, however, also indicates that there is diminishing benefit to be derived with temperature increases at upper levels, especially after the initial temperature rise stage is passed. It is suggested that when deciding the platen temperature, the manufacturer should first determine the maximum platen temperature that is not harmful to the board quality, and then choose the most highest economic platen temperature below that maximum.

F. Immediate Application of Results

As indicated earlier, current operational practice interpretation needs concern itself primarily with results pertaining to the initial temperature rise stage.

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