CONSOLIDATION OF FLAKEBOARD MATS UNDER THEORETICAL LABORATORY PRESSING AND SIMULATED INDUSTRIAL PRESSING

Siqun Wang
Assistant Professor

and

Paul M. Winistorfer†
Professor and Director
The Tennessee Forest Products Center
The University of Tennessee
PO Box 1071
Knoxville, TN 37901-1071

(Received December 1999)

ABSTRACT

To achieve a more fundamental understanding of material behavior during the pressing process, a radiation-based system for measuring density of wood composite mats during consolidation is used to build *in-situ* cross-sectional density distributions of flakeboard mats with pressing time. The fundamentals of densification within flakeboard mats during hot and cold pressing are discussed in this paper. The pressing schedules included theoretical laboratory pressing schedules and schedules simulating industrial pressing. All tests were conducted at either ambient or 204°C temperature. The results include stress relaxation of flakeboard mats during cold and hot pressing, stress-strain behavior, *in-situ* density-strain behavior, and *in-situ* cross-sectional density distributions of flakeboard mats with pressing time. Results of laboratory studies indicate that the stress relaxation during hot pressing after the press reached final position was much quicker than during cold pressing. The observed stress-strain responses of flakeboard mats in hot pressing and cold pressing were similar, characterized by a long stress plateau followed by a rapid increase in stress and an immediate fall-down after the press reached final position. The process to simulate the industry operation resulted in another stress plateau. The stress-strain responses of flakeboard mats were characterized by a long stress plateau followed by a rapid increase in stress, and an additional high stress plateau followed by an immediate fall-down after the press reached final position. There was no clear indication that the maximum gas pressure attained is affected by press closing time.

Keywords: Densification, consolidation, density profile, compression, *in-situ* measurement, flakeboard, pressing, radiation, moisture, bonding, resin, unsteady state.

INTRODUCTION

Hot pressing is a process of pressing a mat between hot platens or hot rollers of a press to compact and set the mat structure by simultaneous application of heat and pressure. One of the major objectives of hot pressing is to achieve a designed panel density and thickness. Hot pressing also results in the spatial density distribution within a panel, especially the vertical density distribution (Harless et al. 1987; Kelly 1977; Wang 1986, 1987; Winistorfer et al. 1998, 2000; Winistorfer and Wang 1999). The density changes during hot pressing have been characterized by many terms, for example consolidation, compaction, compression, and densification. Wang and Winistorfer (2000) indicated that the vertical density profile of OSB is formed from a combination of actions that occur both during consolidation and also after the press has reached final position (i.e., thickness). The term "densifica-

† Member of SWST.

Wood and Fiber Science, 32(4), 2000, pp. 527–538

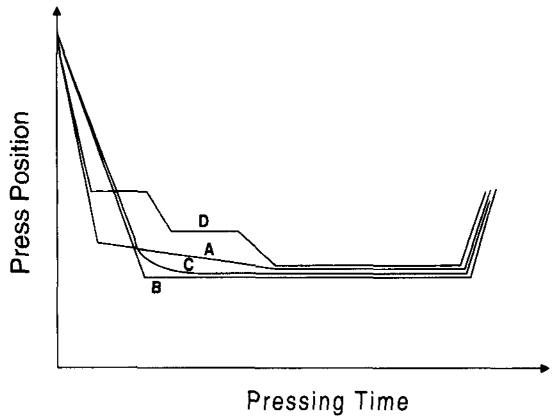

FIG. 1. Schematic diagrams of platen position during hot pressing using different pressing schedules. Schedules shown are: A creep closing schedule for MDF pressing, B theoretical one-step pressing schedule, C typical OSB industrial pressing schedule, and D three step-closing schedule for both OSB and MDF pressing.

tion" will be used throughout this paper to explain the density change within a mat during the whole pressing cycle.

The resulting shape of the density profile after pressing is influenced by three major factors: furnish moisture condition, mat structure, and the pressing environment. There are many underlying material and processing factors that can impact the formation and changes in the density profile. Pressing condition parameters include press closing time, press type, press temperature, press opening schedule, and mat structure.

To achieve a more fundamental understanding of material behavior during the pressing process, several researchers have investigated and described the effects of mat structure on composite performance (Steiner and Dai 1994; Lang and Wolcott 1996a). Other researchers have modeled the compressive stress-strain behavior of many natural and synthetic cellular materials (Wolcott 1989; Dai and Steiner 1993; Lang and Wolcott 1996b; Lenth and Kamke 1996a, b). The experimental results from the authors (Wang and Winistorfer 2000) showed not only stress-strain behavior, but also *in-situ* density-strain behavior.

Some stress-strain models were based on

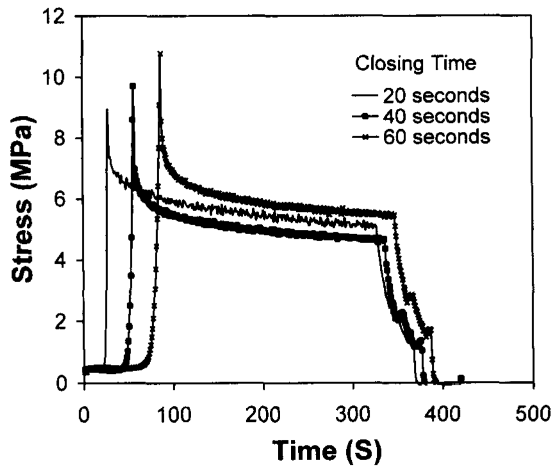

FIG. 2. Stress relaxation of flakeboard mats during cold pressing.

cold pressing and some other references did not clearly indicate that stress-strain behavior models were based on hot pressing or cold pressing (Dai and Steiner 1993; Lang and Wolcott 1996a, b). Heating does increase plasticization of wood and consequently affects the stress-strain behavior of the mat. No publication addressed a comparison of the effect of hot and cold pressing on the stress-strain behavior of the mat.

Figure 1 shows schematic diagrams of platen position during hot pressing. Schedule B in

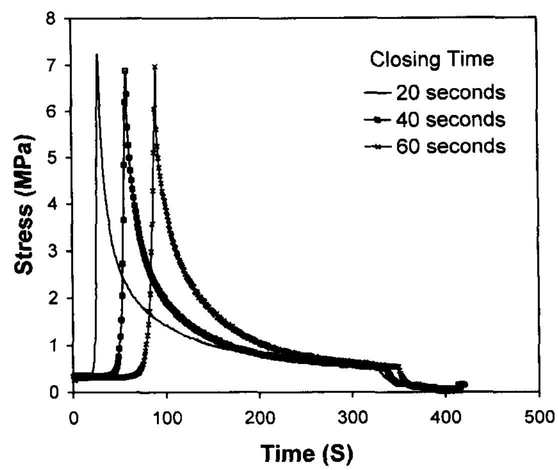

FIG. 3. Stress relaxation of flakeboard mats during hot pressing.

Fig. 1 represents a typical pressing schedule used by many researchers. Schedule B is an ideal hot-pressing schedule, which is typically reflected by a continual closing period under a constant closing speed and final press position period. However, industrial pressing schedules are more complicated than schedule B. The position of the moving platen is generally determined by the computer-based position-control system or pressure-control system. The pressure-control system is commonly used in plywood production. Schedule C in Fig. 1 is a typical pressing schedule used in OSB production. Industrial pressing using the position-control system does not always mimic laboratory press closing due to hydraulic system limitation. The press quickly closes to a position near final panel thickness, and then closing speed slows as the press reaches maximum pressure. While the press maintains maximum pressure, press platen movement is dependent on wood plasticization and further densification. In order to manipulate the end-product density profile attributes, other pressing schedules have been or will be used in the panel industry. For instance, schedule A includes a creep closing for MDF pressing (Park et al. 1999), and schedule D is a step-closing schedule for both OSB and MDF pressing (Wang et al. 2000a–c).

In this report, the fundamentals of densification within flakeboard mats during hot and cold pressing are discussed. The pressing schedules included theoretical laboratory pressing schedules and a schedule simulating the industrial pressing operation.

MATERIALS AND METHODS

Mat preparation

Aspen OSB furnish was procured from an industry mill and was conditioned to 7.0% moisture content. The target panel density was 0.608 g/cm^3, and target panel thickness was 18.3 mm. Mats measured 356 mm by 356 mm, 432 mm by 432 mm, or 560 mm by 560 mm for hot pressing and 152 mm by 356 mm for cold pressing. There was no flake orientation during mat forming. A commercial liquid phenol-formaldehyde resin was applied to the furnish at a rate 3% solids based on oven-dry wood weight in a rotating blender. A 1% wax application was used. The prepress moisture content of furnish was 9.8%.

A special mat-forming technique was used that incorporates a collapsible forming box, in which the mat is formed between two pieces of OSB panel material. The mat is then trimmed to final desired size while it is held prepressed between the OSB panel material. This technique allows for trimming the loose edge of the mat prior to pressing and was developed specifically for use with our in-press radiation monitoring system that requires a well-formed mat edge for enhanced *in-situ* radiation measurement accuracy.

Pressing and measuring conditions

All mats for hot-pressing experiments were produced with a platen temperature of 204°C, a pressing cycle of 360 s, and press closure time of 20, 40 or 60 s. The position of the moving platen is determined by a programmable logic position-control system. The other mats for cold-pressing experiments were produced at room temperature, a pressing cycle of 360 s, and press closure time of 20, 40, or 60 s. Closure time was defined as the time required to reach final position from the initial contact of the mat with the upper platen for the up-acting press. In order to simulate industrial pressing, 432-mm by 432-mm (marked as schedule A) and 560-mm by 560-mm (marked as schedule B) mat sizes and a 20-s closing time were chosen based on the preliminary experiments.

The three *in-situ* radiation beams for density measurements during hot pressing were located at three different positions of the mat thickness for each closing time, respectively (Winistorfer and Wang 1999; Winistorfer et al. 1998, 2000). A gas-pressure probe with a thermocouple was placed at the center of the mat cross section. The press hydraulic pressure was also recorded for each mat. The press con-

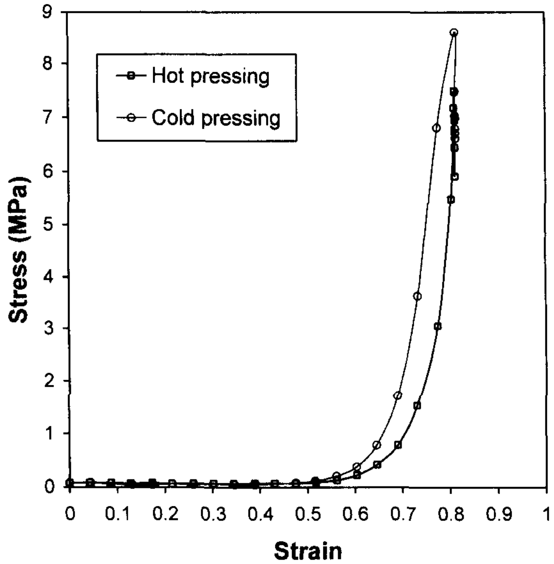

FIG. 4. Stress-strain relationships for cold and hot pressing at the 20-s closing time.

trol system, radiation monitoring system, and press monitor system allow radiation count data, press position, ram pressure, gas pressure, and temperature to be recorded in real time.

To measure *in-situ* density changes through more of the mat cross section than allowed by a single scan using the fixed-position radiation beams, the three fixed radiation beams were repositioned in slightly different locations for subsequent press runs on identical mats. The *in-situ* radiation beams were located at positions of 16.3%, 50%, and 83.7%; 29.3%, 58.7%, and 88%; and 20.6%, 50%, and 79.3%, respectively.

RESULTS AND DISCUSSION

Stress relaxation of flakeboard mats during cold or hot pressing

Figure 2 shows the average stress reading recorded during cold pressing for each of the three closing times. The relaxation curves displayed for the various closing times were all of a similar nature: rapid stress development and characteristic stress relaxation after the press reached final position or thickness. As

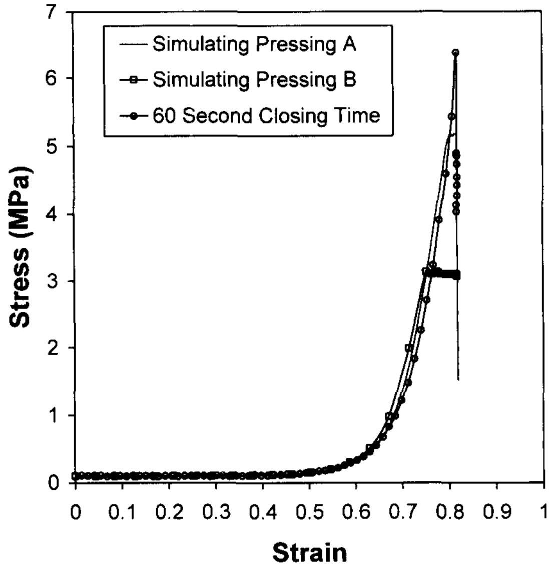

FIG. 5. Stress-strain relationships for the 60-s closing time, simulating schedule A (36-s real closing time) and B (88-s real closing time).

the closing time increased from 20 s to 60 s, the counter pressure (i.e., resistance of the mat to compression force) increased. Wood is a heterogeneous material that is composed of anisotropic cells. When wood is compressed, both elastic collapse and fractures will occur in the cell walls. The quicker press closing times result in quicker status changes from elastic collapse to fractures in the cell walls

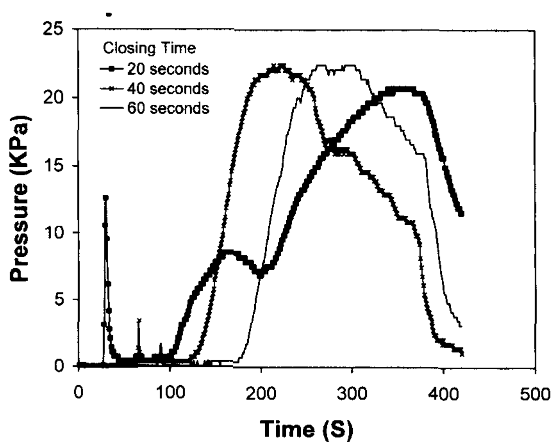

FIG. 6. Gas pressures of flakeboard mats during hot pressing.

and consequently result in a lower pressure to reach the final panel thickness.

Figure 3 shows the average stress reading recorded during hot pressing for each of the three closing times. Stress relaxation during hot pressing after the press reached final thickness occurred sooner than during cold pressing. The stress on the mat needed to maintain the final position during hot pressing decreased 73.0% for the 20-s closing time, 70.7% for the 40-s closing time, and 68.2% for the 60-s closing time from the peak point 40 s after the press reached final position, respectively. By comparison, the stress on the mat during cold pressing decreased only 30.7% for the 20-s closing time, 43.0% for the 40-s closing time, and 41.4% for the 60-s closing time from the peak point 40 s after the press reached final position, respectively. Compared to the stress relaxation of hot-pressed particles (Adcock and Irle 1996), stress relaxation of the mat during hot pressing after the press reached final thickness occurred more quickly than that for the individual particles. This implies that stress relaxation of the mat during hot pressing is not only the result of wood plasticization, but is also affected by horizontal mass movement.

Figure 3 also clearly shows that the press runs carried out at the 204°C temperature fostered plasticization of wood furnish, and therefore the peak stress exhibited is significantly lower than the cold pressing. The peak stress during hot pressing slightly decreased as the press closing time increased. The long closing time causes the mat surface layers to be warmer before the press reaches final position and consequently results in high plasticization of the surface layers. As a consequence of wood plasticization, stress relaxation should result in significantly lower counter pressure. This implies that the longer closing time helps increase core temperature before the press reaches final position and consequently decreases the peak stress.

Stress-strain behavior

The compressive stress-strain relationships of flakeboard mats for hot and cold pressing for a 20-s closing time are shown in Fig. 4. The observed stress-strain responses of flakeboard mats in hot and cold pressing were similar, characterized by a long stress plateau followed by a rapid increase in stress and an immediate fall-down after the press reached final position. The long stress plateau resulted from collapse of between-flake voids. Both mats in cold and hot pressing showed a similar stress-strain response in the plateau region, which continues to a strain level of approximately 0.52.

The increased rates in stress corresponding to densification of the wood component were different for hot and cold pressing (Fig. 4). A hot-pressed mat will tend to be more plastic than a cold-pressed mat, thus requiring less compressive stress in the early stages of consolidation and achieving a higher strain before densification begins. The peak stress in the hot mat when the press reached final position was 7.49 MPa and 14.9% less than 8.61 MPa of the cold mat.

The compressive stress-strain relationships for flakeboard mats with a 60-s closing time and simulating the industrial pressing operation are shown in Fig. 5. The observed stress-strain responses of flakeboard mats with a 60-s closing time were still characterized by a long stress plateau followed by a rapid increase in stress and an immediate fall-down after the press reached final position. The two processes to simulate the industrial pressing operation resulted in an additional plateau. The stress-strain responses of flakeboard mats were characterized by a long stress plateau followed by a rapid increase in stress, another high stress plateau followed by an immediate fall-down after the press reached final position. The period of high stress plateau was affected by wood plasticization resulting from heat transfer.

Gas pressure

The results for the measured mat gas pressures and temperatures at the core layer are shown in Figs. 6 and 7. A longer press closing

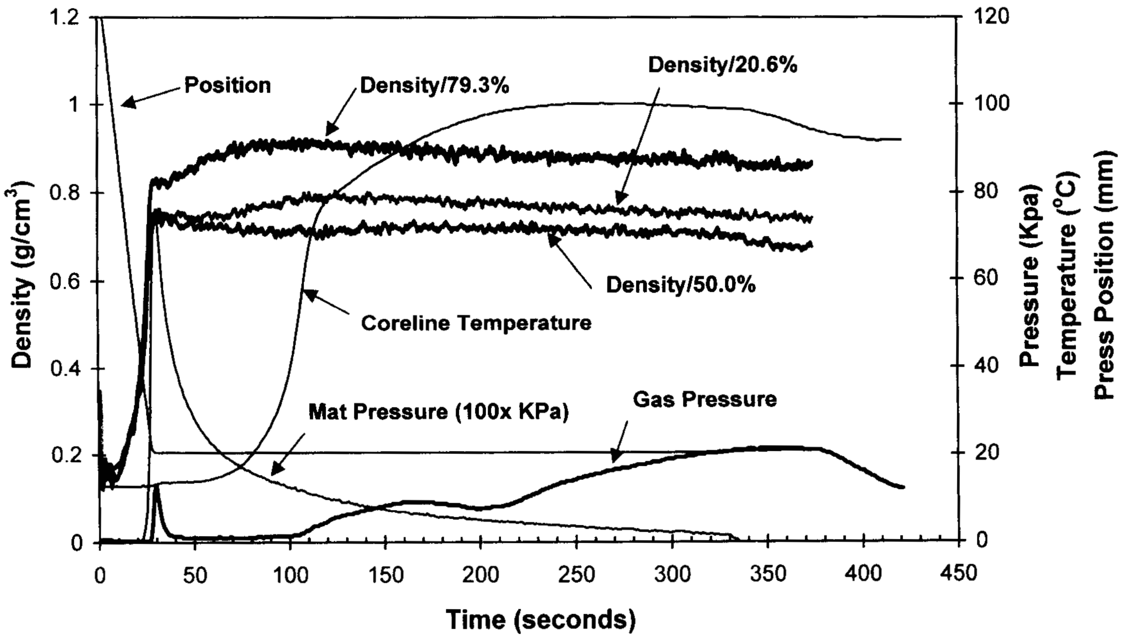

FIG. 7. *In-situ* density profiles and pressing pressure in the flakeboard mat using the 20-s closure time.

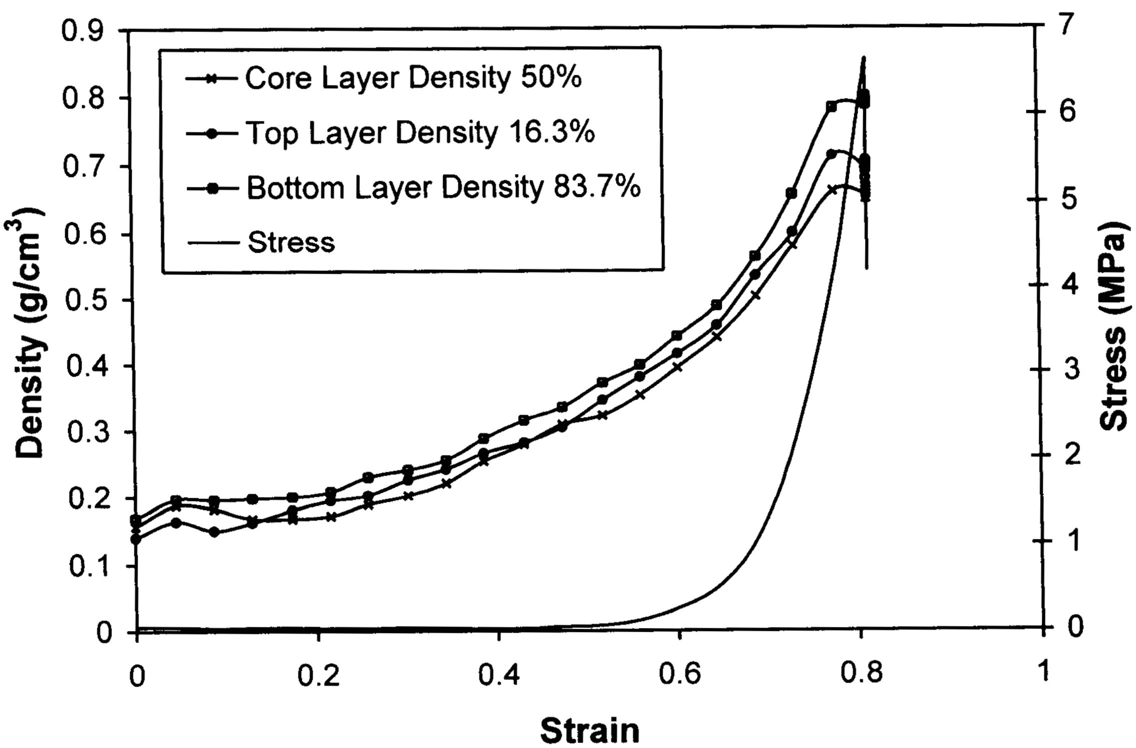

FIG. 8. Stress-strain and *in-situ* densities-strain relationships for the 20-s closing time.