

FUNDAMENTALS OF VERTICAL DENSITY PROFILE FORMATION IN WOOD COMPOSITES. PART III. MDF DENSITY FORMATION DURING HOT-PRESSING

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ABSTRACT

The formation characteristics of the vertical density profile of MDF are presented herein. Results of laboratory studies indicate that the vertical density profile of MDF is formed from a combination of actions that occur both during compaction and also after the press has reached final position. The methodology, which was used to describe the formation of the density profile for OSB that used two periods and five stages, can also be used to describe the density profile formation of MDF mats. There was a clearer surface layer consolidation stage for MDF mats when compared to OSB mats. At least 58% of the area in an MDF mat was in “spring status” when the press reached 120% of final panel thickness. The observed stress-strain response of MDF mats in hot-pressing with the one-step closing schedule was similar to OSB pressing. This was characterized by a long stress plateau followed by a rapid increase in stress, followed by an immediate reduction in stress after the press reached final position. Compared to OSB hot-pressing, the same pressing schedules (traditional or step-closure) did not result in similar MDF density profiles. It appears that high-density surface layers are easier to create in MDF than in OSB.

Keywords: Medium density fiberboard, MDF, *in-situ* measurement, density profile, pressing, OSB, compression, radiation, consolidation.

INTRODUCTION

Our previous paper in this series (Wang and Winistorfer 2000a) discussed the fundamentals

of vertical density profile formation for oriented strandboard (OSB) during hot-pressing. Results indicated that the vertical density profile of OSB is formed from a combination of actions that occur both during consolidation and after the press has reached final position.

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Measurements recorded during pressing clearly indicate that the profile continues to develop after the press has reached final position, and that internal consolidation of the mat continues while the press is maintained at the final position. The reason for the continuation of profile formation is that the mat is in an unsteady state during hot-pressing. Internal mat temperature, moisture content distribution, vapor pressure, layer density, and the compaction stress are all related to the pressing process. In this report, vertical density profile formation characteristics of medium density fiberboard (MDF) are discussed.

BACKGROUND

Medium density fiberboard is one of the most rapidly growing composite board products available in the marketplace. MDF is experiencing increased application in many product areas such as furniture, kitchen cabinets, and ready-to-assemble (RTA) furniture. A key product attribute of MDF is the density profile through the panel thickness. The density profile describes the change in panel density through the panel thickness and usually reflects a high surface density and a lower core density.

A superior MDF panel for laminating, gluing, and finishing should have a density profile in which the face density is considerably higher than the core density. Painting, grain printing, and overlaying the new generation of lightweight papers are also enhanced by a high-density panel surface. The homogeneous core of MDF makes it especially suitable for embossing, molding, and general machining. A uniform density throughout the panel thickness results in better edge-fastening properties. The density profile is correlated to many panel performance characteristics.

Previous research on the MDF pressing (Wang et al. 2001b) showed that the densities of the three layers increased quickly with almost the same consolidation rates while the press closed from the initial starting position to the first intermediate position in 60 s. After

the press reached the first intermediate position and maintained position, only the bottom layer density continued to increase, and both the top layer and core layer densities decreased significantly. A slight decrease was found only on the OSB core layer while the press maintained an intermediate position (Wang et al. 2000). This implied that the *in-situ* vertical density profile change of MDF during press closing was more pronounced than for OSB.

Figure 1 shows schematic diagrams of platen position during hot-pressing. Schedule B in Fig. 1 represents a theoretical OSB pressing schedule, which is typically reflected by a continual closing period under a constant closing speed and final press position period. The industrial pressing schedules are more complicated than in schedule B. Industrial pressing using a 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. OSB is made of flakes and is not compressed easily. The press closure time is generally 20 to 60 s, and the pressing temperature is about 200°C. Phenol-formaldehyde (PF) and/or diphenyl-methylene diisocyanate (MDI) resins are commonly used for OSB production. Compared with OSB mats, MDF mats composed of fibers can be easily compressed, even under the lower pressing temperature (about 160–180°C) required by urea-formaldehyde (UF) resin. To achieve designed vertical density profile, Schedule A (Fig. 1) is widely used in the MDF production (Maloney 1993; Park et al. 1999). The pressing strategy uses a step system, rapidly bringing the press to a thickness about 30% greater than the final targeted panel thickness. This produces a panel with a high-density surface. Subsequent step is a creep closure that slowly brings the panel to final thickness. Total press closure time of MDF is about 60

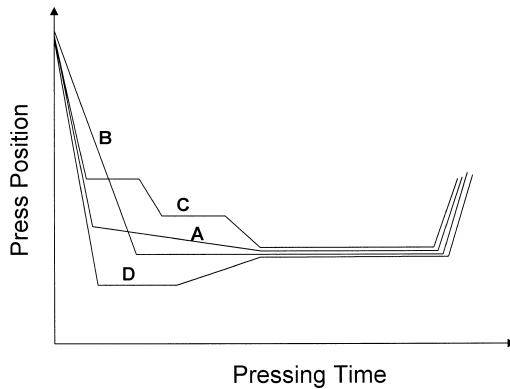


FIG. 1. Schematic diagrams of platen position during hot-pressing using different pressing schedules. Schedules shown are: A—creep closing schedule for MDF pressing, B—typical OSB industrial pressing schedule, C—three step-closing schedule for both OSB and MDF pressing, and D—over-pressing schedule for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

to 200 s, which is much longer than OSB production. In order to manipulate the end-product density profile attributes, the authors developed other pressing schedules. Schedule C is a step-closing schedule for both OSB and MDF pressing (Wang et al. 2000, 2001b). Schedule D is an over-pressing schedule for pressing thin MDF panels (Wang et al. 2001a). Although the pressing of MDF is complicated and different from OSB production, the published literature is somewhat limited as related to MDF pressing and vertical density profile formation.

EXPERIMENTAL METHOD

Board fabrication

Commercial fiber mats used for the experiments were from an MDF mill located in the southern United States, which uses primarily a mixture of southern pine furnish (*Pinus taeda*, *Pinus elliottii*, and *Pinus palustris*). The 559-mm by 559-mm fiber mats were directly cut from 1.5-m by 5.5-m industrial mats at the forming stage of producing line after pre-pressing. The fiber includes urea-formaldehyde resin and wax. The fiber mats were bagged in plastic bags and quickly shipped to

TABLE 1. Pressing schedules and panel information.

Panel no.	Pressing schedules	Total closure time (s)	Schedule description
A	Conventional	200	15 s to 125%; 185 s from 125% to 100%
B	One-step	175	175 s to 100%
C	Three-steps	165	15 s to 130%; 40 s at 130%; 45 s from 130 to 115%; 40 s at 115%; 25 s from 115% to 100%

our lab and pressed into panels the same day. Each mat was trimmed to a final size at our lab. The target panel density was 0.752 g/cm³. The target panel thickness was 19.1 mm. The trimmed mat size was 356 mm by 356 mm. Two sheets of 0.8-mm-thick aluminum cauls were placed on the bottom and top of the mat during pressing.

Pressing schedules and in situ density profile measurement

Every mat was produced at platen temperature 160°C and a total pressing cycle of 400 s. The detailed pressing schedules are shown in Table 1. To indicate *in-situ* density changes through mat thickness, three mats were separately pressed while *in-situ* radiation beams were located at three different sets of positions. The first set of positions was 20.8%, 50%, and 79.2% of mat thickness, measured from the top of the mat; the second position set was 27.0%, 54.2%, and 81.2%; and the third position set was 31.2%, 62.5%, and 93.8% (Winistorfer et al. 2000). The position of the platens was determined by position-control. The computer control and monitoring system allowed the pressing procedure to be programmed. Pressure and coreline temperature data were recorded during pressing. Each condition had two replications.

RESULTS AND DISCUSSION

Formation of MDF vertical density profiles

Based on the fundamental research of OSB, Wang and Winistorfer (2000a) proposed a

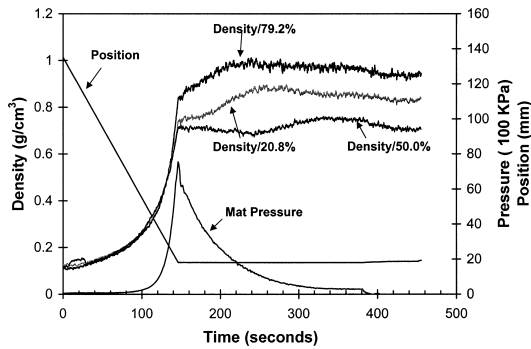


FIG. 2. *In-situ* density profiles, pressing pressure in Schedule B (one-step closing, 175-s total closure time).

methodology to describe the formation of the density profile into two periods and five stages. Period I is the time period during closure before the press has reached final position, and includes two stages: (1) uniform consolidation stage among different layers before pressing closing and; (2) non-uniform consolidation stage among different layers before the press has reach final position. Period II is that time period after the press has reached final position and includes three stages: (1) surface layer consolidation; (2) core layer consolidation; and (3) “springback” of the mat while the press opens. Both periods and all five stages influence the resulting density profile.

Figures 2 and 3 illustrate the two periods and five stages during the formation of the density profiles in MDF mats. Figure 2 illustrates the *in-situ* density profiles in the MDF mat pressed at 175-s closure rate (Schedule B). The three separate lines depict the three horizontal-plane density measurements through the mat. The densities of three layers increased quickly with almost the same consolidation rates before the press reached final position. After the press reached final position and was maintained at final position, the densities of both face layers (top and bottom layer) continued to increase. Bottom density rose much quicker than top layer because of the preheating of the mat bottom side during manual mat load. There was significant decrease on the core layer, which indicated that there was significant spring zone in the mat core

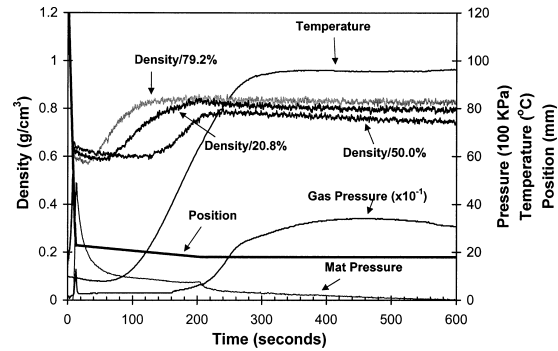


FIG. 3. *In-situ* density profiles, coreline temperature, gas and pressing pressure in Schedule A (conventional closing, 200-s total closure time).

area. This period is called “surface layer consolidation stage.” When pressing time reached 240 s, the core layer density stopped decreasing and started to rise again. At the same time, the densities of both face layers (top and bottom layer) started to decrease. This period is called “core layer consolidation stage.” This period ends after the mat has been pressed for 350 s.

Figure 3 contained the *in-situ* density profiles, pressing pressure, and mat coreline temperature in an MDF mat pressed using a different technique. The technique was to rapidly compress the mat from starting position to a thickness 25% greater than the final targeted panel thickness and hold for 15 s and then slowly bring the mat to final position and hold for 185 s. The densities of three layers increased quickly with the same consolidation rates before the press reached a thickness that was 125% of final targeted panel thickness. The period in stage 2 (non-uniform compression) was shorter when compared to OSB hot-pressing. After the press reached a thickness of 125% of targeted panel thickness and the slow continual closing period started, densities of three layers stopped rising and started to decrease. The measured location of the bottom layer was 20.8% of the mat thickness farther from mat bottom surface. This indicated that at least 58% of the area in the mat was “spring status” when the press was in a slow continual closing period. The period when the bottom

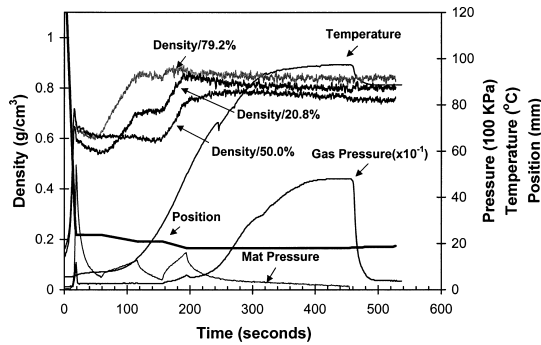


FIG. 4. *In-situ* density profiles, coreline temperature, gas and pressing pressure in Schedule C (three-step closing, 175-s total closure time).

layer was in “spring status” was much shorter. The top layer and core layer stopped “spring status” and densities increased. This phenomenon indicated that the spring zone in the mat core area was continually reduced until it eventually disappeared. After the press reached final position, there still was a slight increase of density in the core layer. At the same time, both top and bottom layer densities were slowly reduced. This period was known as “Stage 4.”

Figure 4 illustrates the *in-situ* density profiles, pressing pressure, and mat temperature in the MDF mat pressed at a three-step closing schedule (Schedule C). Total closing time was 240 s that included 40 s at the first intermediate position and 40 s at the second intermediate position. Each intermediate position was 130% and 115% of final target panel thickness, respectively. The densities of the three density layers increased rapidly with the same consolidation rates before the press reached intermediate position. After the press reached the first intermediate position and was maintained at that position, the densities of three layers quickly started to decrease. When the press started the second closure step, the bottom layer density immediately stopped decreasing and started to increase again. During the second closure step, the top layer density also started to increase. When the press started the third closure step and coreline temperature reached 26.7°C, the core layer density stopped

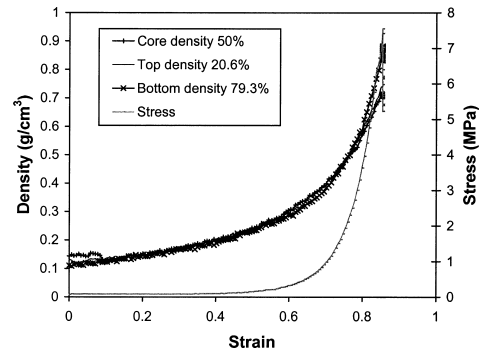


FIG. 5. *In-situ* densities-strain and stress-strain relationships for the one-step closing Schedule B (one-step closing, 175-s total closure time).

decreasing and started to increase again. At this inflection point, core layer density was 0.601 g/cm³, which was 18.9% less than the peak density of 0.741 g/cm³ of core layer at the final closing point. The phenomenon of “spring zone” in the mat core area in panel C which was pressed under a step-closing schedule was more pronounced than in panel A, which was pressed under a traditional pressing schedule. Panel C “spring zone” was also more significant than in OSB pressing (Wang and Winistorfer 2000a; Wang et al. 2000 and 2001b). It needs to be noticed that OSB panels were pressed under the higher pressing temperature 200°C and the OSB panels were 12.5 mm thick, thinner than MDF panels. MDF panel C was maintained at an intermediate position during pressing, which resulted in larger mat thickness, larger temperature gradient, and compression differences in the vertical direction. After the press reached final position, there was a slight increase in the core layer with corresponding reductions in both the top and bottom face layers.

In-situ density-strain behavior and stress-strain relationships

Characteristic mechanical response for MDF mats in compression and resulted *in-situ* densities are shown in Figs. 5–10. *In-situ* densities-strain and stress-strain relationships for the one-step closing Schedule B are shown in

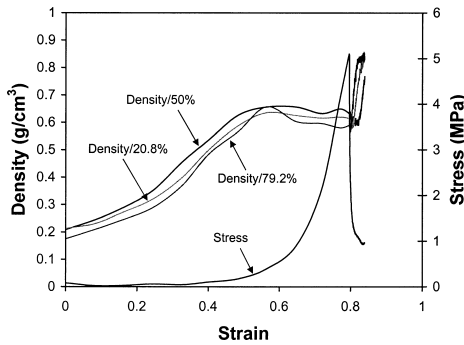


FIG. 6. *In-situ* densities-strain and stress-strain relationships for the conventional Schedule A (conventional closing, 200-s total closure time).

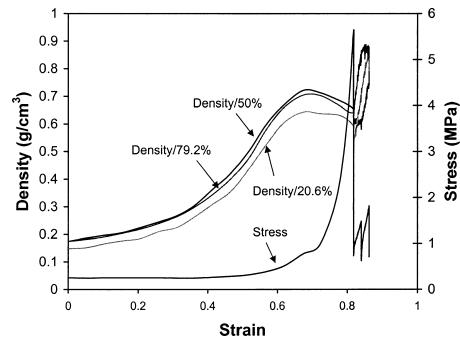


FIG. 7. *In-situ* densities-strain and stress-strain relationships for the three-step closing Schedule C (three-step closing, 165-s total closure time).

Fig. 5. The observed stress-strain response of MDF mats in hot-pressing with the one-step closing schedule was similar to OSB pressing. This was characterized by a long stress plateau followed by a rapid increase in stress and an

immediate reduction in stress after the press reached final position (Wang and Winistorfer 2000b). The long stress plateau resulted from collapse of “between-fiber” voids. The rapid increase in stress corresponded to densification

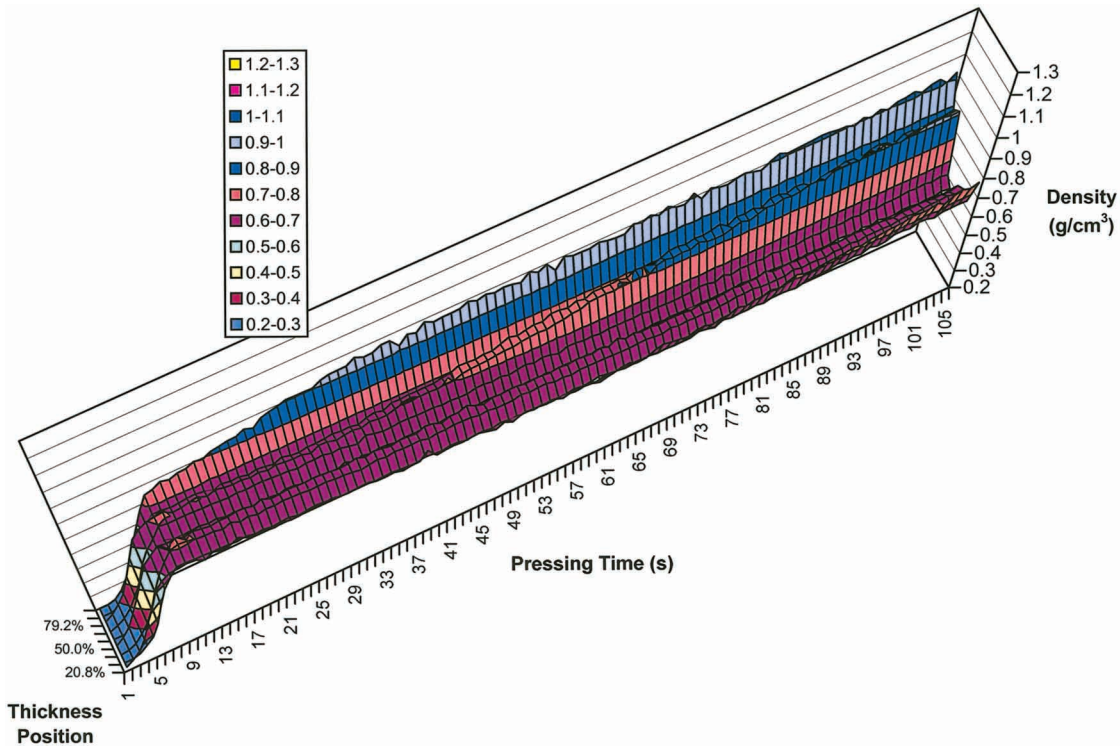


FIG. 8. *In-situ* cross-section density distribution during 0 to 105 s of consolidation period for the conventional closing Schedule A. Each data point represents an average at a 0.7-s interval calculated from the real time data taken as eight measurements per second.

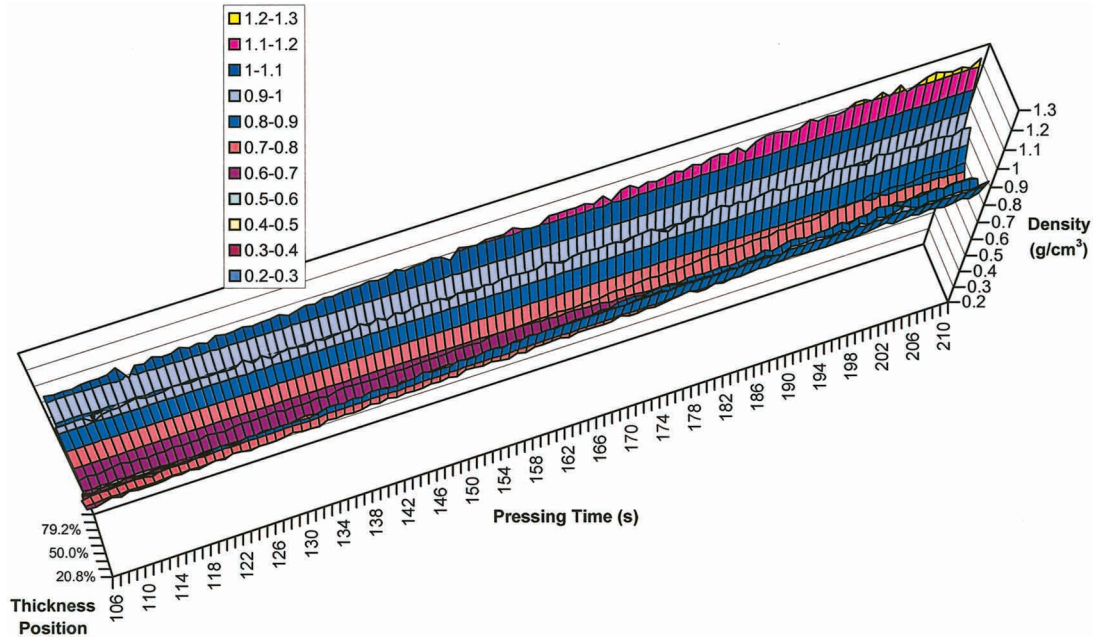


FIG. 9. *In-situ* cross-section density distribution during 106 to 210 s of consolidation period for the conventional closing Schedule A. Each data point represents an average at a 0.7-s interval calculated from the real time data taken as eight measurements per second.

of the wood component. Figure 5 shows that during nonlinear cellular collapse, *in-situ* densities using the one-step closing schedule tended to increase at the same rate before the strain reached 0.78. The rate of density increase among the three layers showed different trends after the strain reached 0.78. At final closure position, maximum density and minimum density were achieved in the bottom and core layers, respectively. No distinct elbow in the *in-situ* density-strain relationship was found in OSB pressing.

In-situ densities-strain and stress-strain relationships for the conventional closing Schedule A are shown in Fig. 6. This pressing schedule rapidly compacted the mat to a thickness 25% greater than the final targeted panel thickness, and then the mat was slowly brought to the final thickness during a 185-s closing period. The observed stress-strain response of MDF mats in hot-pressing with the conventional closing schedule was characterized by a long stress plateau followed by a

rapid increase in stress and an immediate reduction after the press reached intermediate position. The maximum stress, when the press reached intermediate position, was 5.09 MPa, which was 34.7% lower than 7.80 MPa of panel B which was pressed with the one-step closing schedule.

In-situ densities using the conventional closing schedule tended to quickly increase at the same rate before the strain reached 0.50 (Fig. 6). At the point of the strain 0.5, the long stress plateau ended and the stress started to increase quickly. A distinct elbow was noted in each of the *in-situ* density profiles after the long stress plateau ended and the stresses increased. This implied that the *in-situ* densities may increase at the same rate during the long stress plateau that resulted from collapse of between-fiber voids. There was a uniform compression stage. When densification of the wood component occurred, the nonuniform compression stage started. There was a slight density decrease in each monitoring location

before the press reached intermediate position. The top and bottom *in-situ* radiation beams for density measurement during hot-pressing were positioned at 20.8% and 79.2% of mat thickness, respectively. It was possible for the outside mat layer to have had a faster rate of density rise. This implied that about 60% of mat area was in spring status during densification of the wood fiber component. When compared with OSB mat pressing, the spring symptom occurred only during adjustment period and after the press had reached final position, which continued until the end of the pressing cycle (Wang and Winistorfer 2000a). After the press reached the intermediate position, the stress on the mat was immediately reduced and the density for each location started to increase (Fig. 6). At the final closure position, maximum density and minimum density were achieved in the bottom and core layers, respectively.

In-situ density-strain and stress-strain relationships for the three-step closing schedule (Schedule C) are shown in Fig. 7. This pressing schedule rapidly brought the mat after insertion into the press to the first intermediate position, which represented a thickness 30% greater than the final targeted panel thickness (Table 1). After holding at the first intermediate position for 40 s, the press closed to a second intermediate position (15% greater than the final targeted panel thickness) during an additional 45-s period. After holding at the second intermediate position for 40 s, the press moved to the final position in a 25-s closing period. The observed stress-strain response of MDF mats in hot-pressing with the three-step closing schedule was characterized by a long stress plateau followed by a rapid increase in stress, followed by an immediate reduction after the press reached the first intermediate position. The second and third closure also made a minor stress peak, respectively. *In-situ* densities-strain relationship for the three-step closing schedule (Schedule C) was similar to the conventional closing Schedule A. The only noticeable difference was a

density increase in the core density during the third closure period.

In-situ density changes through mat thickness

Figures 8–9 show *in-situ* density distributions through 20.8% to 93.8% of MDF mat thickness, which was derived with a conventional closure schedule (Schedule A). Figure 8 shows *in-situ* cross-section density distribution during the first 105 s of the consolidation period for Schedule A. Each data point represented an average at a 0.7-s interval. Starting with an initial mat bulk density of 0.15 to 0.26 g/cm³, the density through the mat thickness began to increase quickly with the same consolidation rates before the press reached a thickness 125% of final targeted panel thickness. The densities through the panel thickness were in the range of 0.6 to 0.7 g/cm³ when the press reached a thickness 125% of final targeted panel thickness. Uniform compression of the mat was finished and the period of non-uniform compression begun immediately after the press started the slow closing schedule. The *in-situ* density of the location 93.8% from the bottom side of the mat started to increase earlier than in other locations. The *in-situ* density at the location 93.8% from the bottom side of the mat reached a range of 1.0 to 1.1 g/cm³ density after 105 s of pressing time. Compared with the bottom side of the mat, the *in-situ* density at the 20.8% location on the top side of the mat increased much more slowly. The topside of the mat had a density range of 0.7 to 0.8 g/cm³ after 98 s of pressing time. There was a slight density decrease in the core layer of mat.

Figure 9 shows *in-situ* cross-section density distribution during the 106 to 210-s consolidation period for the conventional closing schedule (Schedule A). During the second half of the closing period, the *in-situ* density at a location 93.8% from the bottom side of the mat was 1.2 to 1.3 g/cm³. At the same time, the *in-situ* density at the location 20.8% from the topside of the mat was the 0.8 to 0.9 g/

cm³. The core layer density increased to a density range from 0.7 to 0.8 g/cm³ at a pressing time of 180 s.

CONCLUSIONS

Results of laboratory studies indicate that the vertical density profile of MDF is formed from a combination of actions that occur both during compaction and also after the press has reached final position. The methodology to describe the formation of the density profile into two periods and five stages based on previous OSB research can also be used to describe the density profile formation in MDF fiber mats. However, there was a clearer surface layer consolidation stage when compared with OSB pressing. For example, at least 58% of area in the MDF mat was in “spring status” when the press reached a thickness that was 120% of the targeted panel thickness.

The observed stress-strain response of MDF mats in hot-pressing with the one-step closing schedule was similar to OSB pressing. This stress-strain response was characterized by a long stress plateau followed by a rapid increase in stress with an immediate reduction in stress after the press reached final position.

Compared to OSB hot-pressing using the same pressing schedules (traditional and step-closure), the MDF density profile was dissimilar to the OSB profile. It appears that high-density surface layers are easier to produce in MDF than in OSB.

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