Effects of Pressing Schedule on Formation of Vertical Density Profile for MDF Panels

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Abstract

A fundamental understanding of mat consolidation during hot pressing will help to optimize the medium-density fiberboard (MDF) manufacturing process by increasing productivity, improving product quality, and enhancing durability. Effects of panel density, fiber moisture content (MC), and pressing schedule on formation of vertical density profile (VDP) during hot pressing were investigated. Different pressing schedules in which the platens were quickly closed to positions of 160%, 140%, 120%, 100%, and 90% of final target thickness then more slowly brought to final target thickness were found to be the most important parameters that affected mat consolidation process. Results indicated that with careful selection of pressing schedule, MDF manufacturers can produce products with designated performances based on VDPs. Results from this study are also needed for eventual verification of various press modeling programs that were recently developed.

Introduction

The first medium-density fiberboard (MDF) plant was built by Allied Chemical in 1966 at Deposit, New York. New applications for MDF are still being discovered daily, and about 40 million cubic meters of MDF is manufactured each year (Maclaren 2005). Production of MDF in the United States increased 14.6% from 2001 to 2002 (Howard 2004). Representing one of the fastest growing wood composite markets, MDF derives its popularity primarily from the furniture and cabinet industries because of its excellent surface and molding performances.

Vertical density profile (VDP), defined as density distribution through the thickness of the panel, is used to characterize surface and molding performances. High-density faces help to produce pitless, smooth, and dense surfaces, which make MDF an excellent substrate for laminating with other materials. Alternatively, uniform and flat density profiles represent homogenous and uniform densification of fibers in the MDF panel, which minimizes loose fiber in the core during the molding process and makes MDF very competitive with solid woods for molding and embossing (Cai at el. 2006). The VDP and its effect on performance directly result from the combined effects of many process parameters, including furnish characteristics (mat moisture and resin contents), pressing temperature, and pressing strategies (Suchland and Woodson 1986, Winistorfer and Wang 1999). Different pressing strategies (different closing rates and steps) are commonly used to manipulate VDP according to the final MDF product application.

The entire series of hot pressing factors are most important in determining the formation of vertical density through the thickness of the panel. Heat energy from the hot platens raises the temperature of the wood fiber mat, softens the mat by plasticizing the wood fibers, and cures the resin binder. The speed of heat penetration into the mat determines mat consolidation, formation of density profile, and press time, which in turn are critical to productivity and development of panel properties such as modulus of elasticity (MOE), modulus of rupture (MOR), internal bonding (IB), and in-service moisture sorption characteristics. The speed of heat transfer depends on a number of process variables. Many individual studies have investigated the effect of process variables on hot-pressing, and several theoretical models have been developed to simulate the hot-pressing process (Dai and Wang 2004, Frazier 2004, Kamke 2004, Humphrey and Bolton 1989, Kamke and Wolcott 1991, Length and Kamke 1996). Although theoretical models provide one type of tool to better understand the hot-pressing process, a simple and practical method to optimize the process would also be very helpful for the wood-based composite industry (Park et al. 1999).

The fundamentals of VDP formation for MDF panels from southern pine fibers during hot pressing were examined using in situ radiation beams (Wang et al. 2004). Two periods (before and after press reaching the final target position) and five different consolidation stages (uniform, non-uniform, surface layers, core layer, and springback after press opening) were proposed to describe the formation of density profile. The effect of step-closing pressing the MDF panel on VDP and performance were extensively examined (Wang et al. 2001a, b). It was found that the ultimate effects of step-closure schedule were due to intermediate step position, time at intermediate position, and the rate of initial press closing speed. Results indicated that the characteristics of VDP for MDF were controlled by a combination of actions that occurred both during mat compaction and after the press reached its final position. The density of both top and bottom layers rose much more quickly than that of the core layer, which in turn resulted in high-density surface layers.

Effect of mat moisture content and final panel density on mechanical performance of MDF panels, heat transfer, internal steam pressure, and VDP were systematically studied (Cai et al. 2006). Panel density had significant effects on almost all the properties examined, whereas mat moisture content (MC) influenced only internal steam pressure, maximum core temperature, and internal bonding. Both panel density and mat MC were found to have no effect on the ratio of maximum face density to minimum core density, which were extracted from VDP data.

The objective of this study was to examine the effect of various pressing schedules and mat MCs on VDP formation and performances of MDF panels made from mixed-species wood fibers. The results will help manufacturers to select the proper pressing schedule to manipulate VDP to optimize the MDF product to its final application.

Materials and Procedures

Mixed-species wood fibers (about 20% each of white pine, birch, maple, basswood, and aspen) were obtained from a commercial fiberboard plant in northern Wisconsin. The fibers were conditioned at two MC levels (6% and 9%) in a closed-loop tube blender by adding a certain amount of moisture to the fiber. Liquid urea formaldehyde (UF) resin with 60% solids content was provided by Georgia Pacific Resin Company. The resin was sprayed on pre-conditioned fibers as they circulated at high speed in a closed-loop tube blender. The relatively dry fibers, circulating at high speed in the tube, were thus prevented from forming into fiber balls, which were normally produced in the drum blender during the addition of the resin. Twelve percent resin, based on the ovendried weight of the fiber, was applied to the fiber for all panels made in this study.

The resinated fibers were laid up by hand into a 508- by 508-mm (20- by 20-in.) mat on a caul plate. The initial MDF mat thickness was about 150 mm, and the target thickness of the panel was 12.7 mm (0.5 in.). The mat, with caul plates on top and bottom, was transferred to a conventional oil-heated press (910 by 910 mm) equipped with a computerized control and data collection system. The press temperature was maintained at 180°C. Press closing occurred in two stages. In the first stage of pressing, the press initially closed until it reached a certain percentage of the final target thickness (12.7 mm), which took about 20 to 25 s. In the second stage, over the next 100 s, the press uniformly moved to its final target position, which corresponded to the mat target thickness. At mat target thickness the core temperature exceeded 100°C, which was considered the minimum temperature for plasticizing the wood fiber and curing the UF resin binder (Cai et al. 2006). The panel was held at the target thickness for 140 s before the press opened gradually over a 40-s period to facilitate slow release of internal steam pressure.

To examine the effects of various pressing schedules, panel density, and mat MC on producing MDF panels, two fiber MCs (6% and 9%) and two panel densities (700 and 770 kg/m^3) were selected based on the normal range of commercial MDF products. For each density and fiber MC level, five different pressing schedules were used: the press initially closed at its full capacity until it reached either 160%, 140%, 120%, 100%, or 90% of the final target position and then uniformly finished closing to the final position (Fig. 1). Factorial design of the three variables, with the levels indicated above, resulted in 20 experimental runs. Eight 50.8- by 50.8-mm (2- by 2-in.) samples were cut from each panel and their VDPs were evaluated on an x-ray-based density profile system. The MOE and MOR samples were conditioned at 23°C and 65% relative humidity for 3 weeks before they were tested according to American Society of Testing and Materials test method ASTM D 1037.

Results and Discussions

During the hot-pressing process, pressing stresses vertically applied to the mat from the press are always the same through the thickness. However, compressive strain through the thickness of the consolidation of the mat is non-uniform due to gradients of heat transfer, moisture movement inside the mat, plasticity of the fiber, and resin curing. Heat transfers into the face layers first and causes the fiber in the face layers to be compressed easily (more strains) when the press pressure is still high. Later, as the heat migrates into the core layer, the heat softens the core fiber, which results in decreased mat pressure, causing less strain. The different compressive strain distribution through the thickness eventually results in uneven mat consolidation patterns, which in turn dictate the final VDP. Usually, face density is higher than core density, which produces an M-shaped VDP. This eventual VDP, which is closely related to both pressing process and mat configuration, has been valuable in evaluating the quality of panels for various uses. The face maximum density, lowest core density, face-to-core density ratio (the maximum face density divided by the minimum core density), and surface thickness (vertical distance from the surface to the position where the maximum face density is located) are often calculated from the VDP data to evaluate the combined effects of heat and moisture on mat consolidation and resin cure, respectively.

Figures 2 to 6 show average VDPs for MDF panels made with different pressing schedules (different initial platen positions from 90% to 160% of the final thickness), different fiber MCs (MC6 = 6% and MC9 = 9%), and different panel densities (LD = 700 kg/cm^3 and HD = 770 kg/cm^3). The initial panel density affected the overall distribution position of density profile but had little impact on the overall shape of VDP. There was no obvious difference of VDPs between 6% and 9% fiber MCs, when the press closed fast (that is, 90% and 100% of final thickness). However, when the initial positions of the press platen were such as to not quickly compress the mat (that is, 140% and 160% of the final panel thickness), rapid heat transfer into the less dense fiber mat seemed to be facilitated. The amounts of steam generated within the mat varied with initial furnish MC prior to pressing and had a noticeable effect on VDP (Figs. 5 and 6). Compared with panel density and mat moisture, the various pressing schedules (different initial platen position) clearly had an effect on the formation of VDP (Fig. 7). For initial positions of the press platen from 140% to 100%, maximum face density increased about 25% and minimum core density decreased about 10%. When the initial platen position was 160%, the VDP was no longer similar M-shaped—multiple peaks appeared in the density profiles (Figs. 6 and 7). The pressing schedule had the obvious impact on VDP shape. Results of this study of MDF panels made from mixed hardwood species fibers confirmed the observation made by Wang et al. (2004) on southern pine fibers that closing the press slowly resulted in flatter density profiles, whereas closing the press more rapidly produced more definitive gradients and a classic M-shaped profile.

Changing the pressing schedules altered the VDP, which in turn determined the panel performance. For example, in an application of molding and embossing where uniform VDP is desirable, the slow press closing (140% or even 160% initial platen positions) should probably be used for producing MDF panels. Previous authors have shown that overall panel density has a significant effect on mechanical properties (Woodson 1977, Hague et al. 1999). However, given the same overall panel density, changing the pressing schedules could also significantly alter the panel mechanical performance. Figure 8 shows results for various mechanical properties relative to the various schedules used in this study. These results are shown as ratios to the results using the pressing strategy set at 100% of the final thickness. Pressing schedule had an obvious impact on mechanical properties. When varying the strategy for closing the press platen from 160% to 90% of the final target thickness, both MOE and MOR values increased almost linearly. When the initial platen position was changed from 140% to 100% of the target thickness, the average MOE and MOR value increased about 25%, while the average IB value decreased about 15%. It was clearly not linear across the entire array of press-closing strategies. There was a relatively large variation in actual IB values (Fig. 8), which we believe is related to the irregular formation of VDPs.

From the analysis of the data (as shown in Fig. 7), it was speculated that MDF panels with a virtually flat VDP could be made by adjusting the initial press platen position between 140% and 160% for the material, MC, and mat densities used in this study. To evaluate this, six different combinations of the initial platen positions (%) and times (s) from the initial positions to the final thickness were used to make some additional panels. Their VDPs are shown in Figure 9. It was clear that an initial plate position of 152% pressed for 100 s produced MDF panels with virtually flat VDPs. Additional studies using an array of different materials, press temperatures, mat MCs, and mat densities are needed to better learn to produce MDF panels with perfectly flat VDPs.

Conclusions

Effect of panel density, fiber MC, and pressing schedule on the formation of vertical density profile (VDP) were systematically investigated. Panel density affected the overall position of density profile but had little impact on the shape of VDP. For the 6% and 9% fiber MCs studied, there were no obvious differences between their VDPs. However, various pressing schedules (different initial platen position) had a major effect on the formation and shape of VDP. With careful selection of pressing schedule, MDF panels could be produced with desirable performances ranging from classic VDPs with dense faces and less dense cores to that having a virtually flat VDP.

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Figure Captions

Figure 1. Pressing schedules showing platen position as percentage of final panel thickness over time.

Figure 2. Density profiles with initial platen position at 90% of panel thickness.

Figure 3. Density profiles with initial platen position at 100% (see Fig. 2 for legend definitions).

Figure 4. Density profiles with initial platen position at 120% (see Fig. 2 for legend definitions).

Figure 5. Density profiles with initial platen position at 140% (see Fig. 2 for legend definitions).

Figure 6. Density profiles with initial platen position at 160% (see Fig. 2 for legend definitions).

Figure 7. Density profiles with different initial platen positions (see Fig. 2 for legend definitions).

Figure 8. Mechanical properties with different pressing schedules.

Figure 9. Density profiles with different pressing strategies (see Fig. 1 for legend definitions).

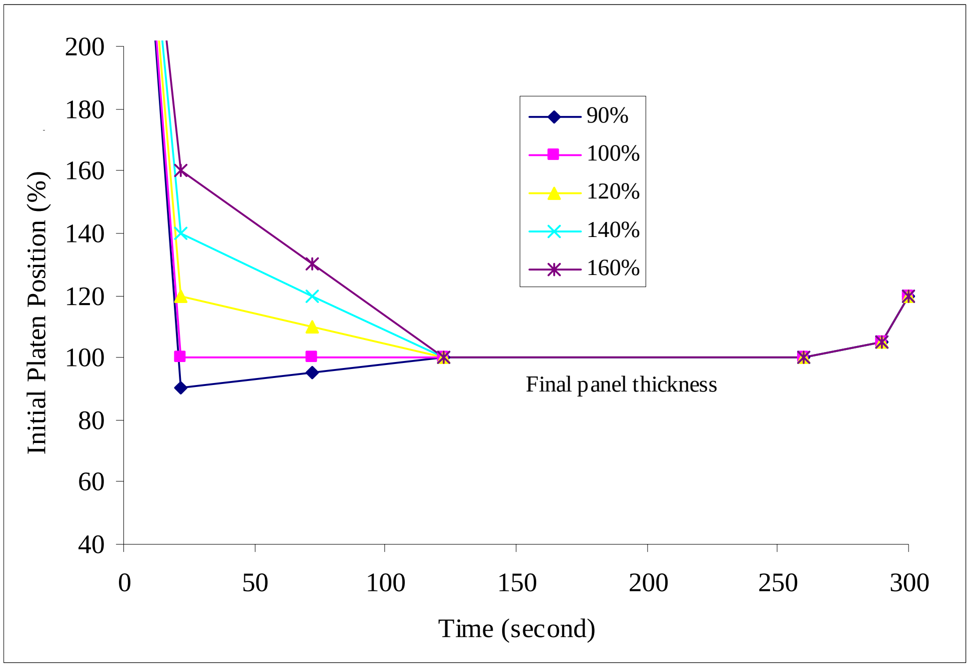

Figure 1. Pressing schedules showing platen position as percentage of final panel thickness over time.

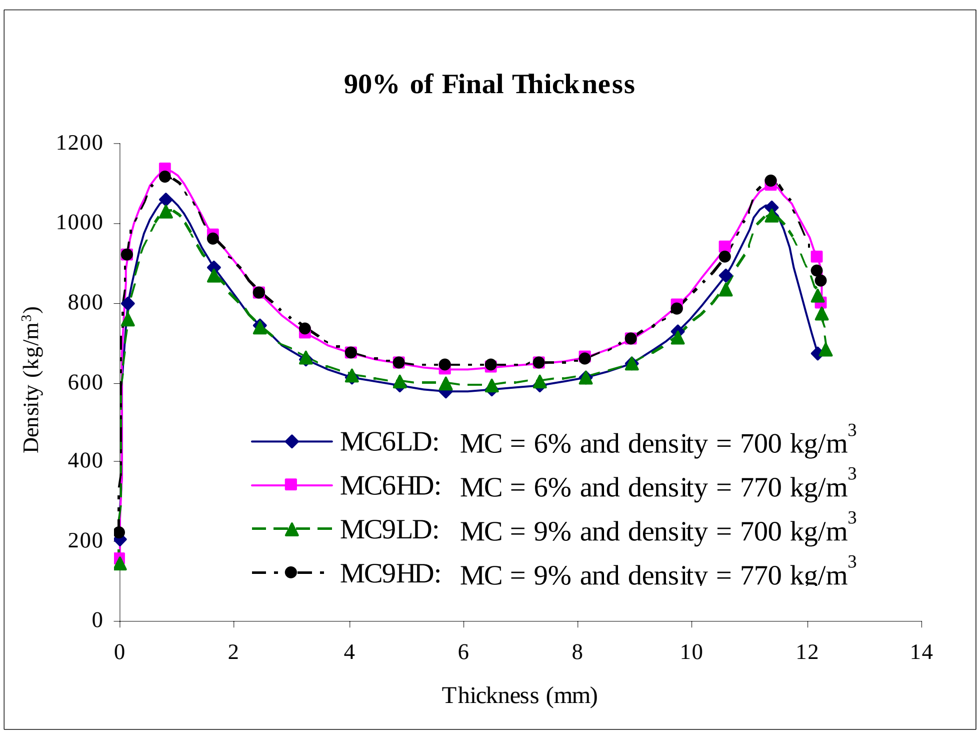

Figure 2. Density profiles with initial platen position at 90% of panel thickness.

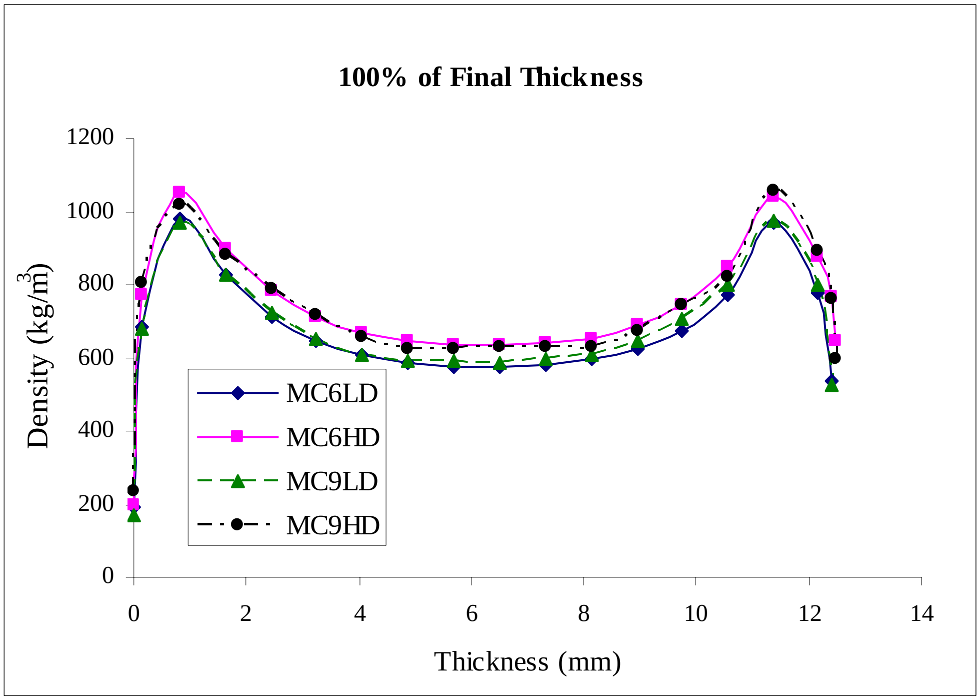

Figure 3. Density profiles with initial platen position at 100% (see Fig. 2 for legend definitions).

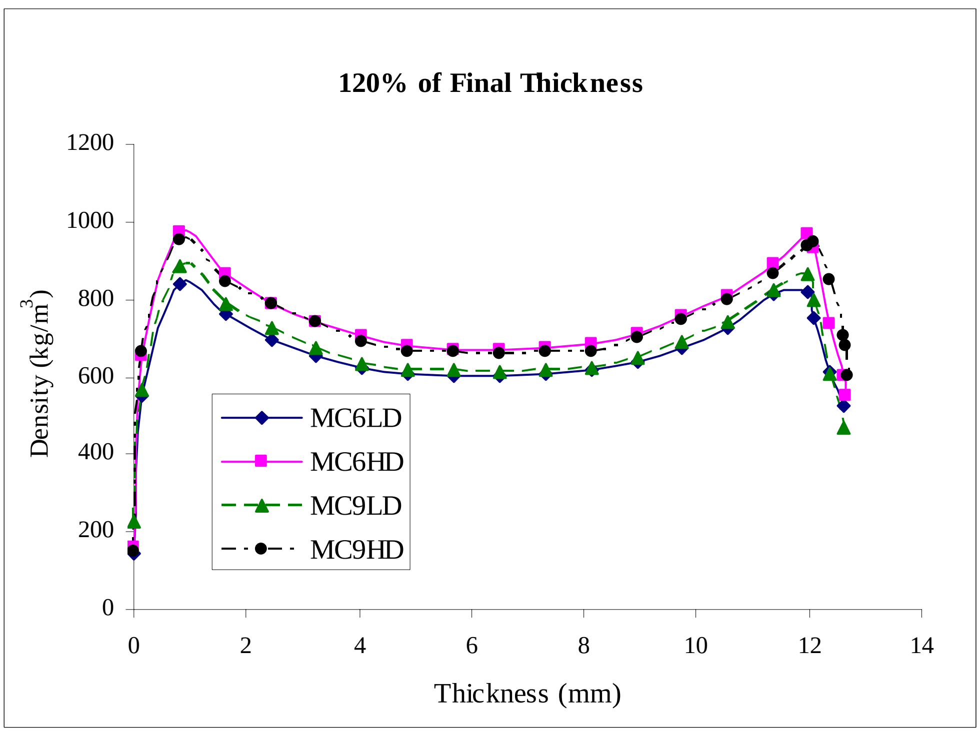

Figure 4. Density profiles with initial platen position at 120% (see Fig. 2 for legend definitions).

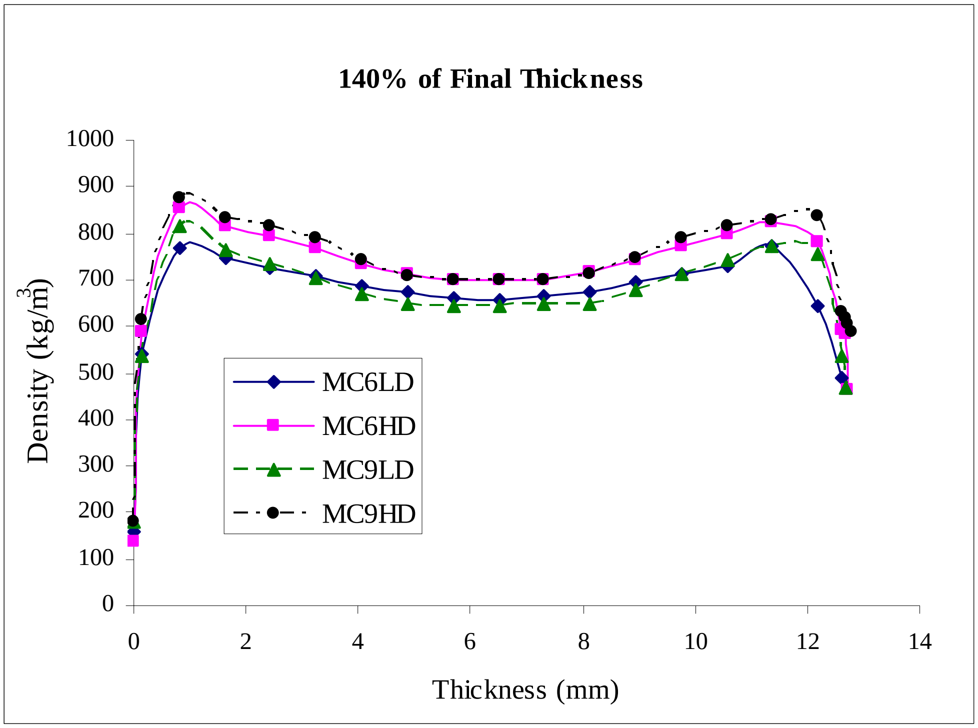

Figure 5. Density profiles with initial platen position at 140% (see Fig. 2 for legend definitions).

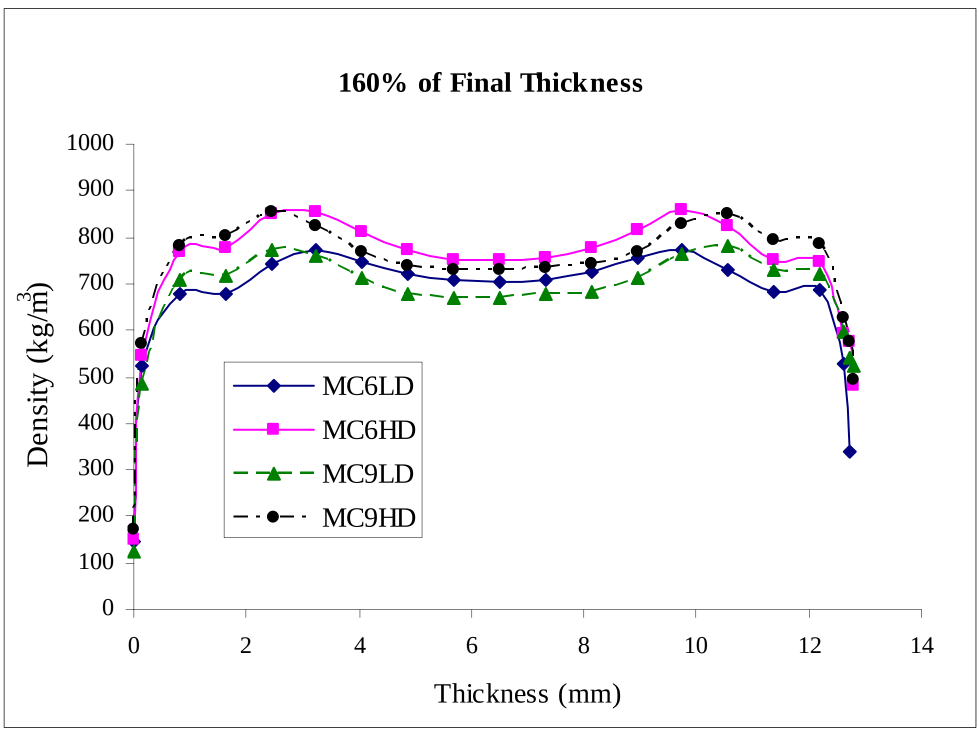

Figure 6. Density profiles with initial platen position at 160% (see Fig. 2 for legend definitions).

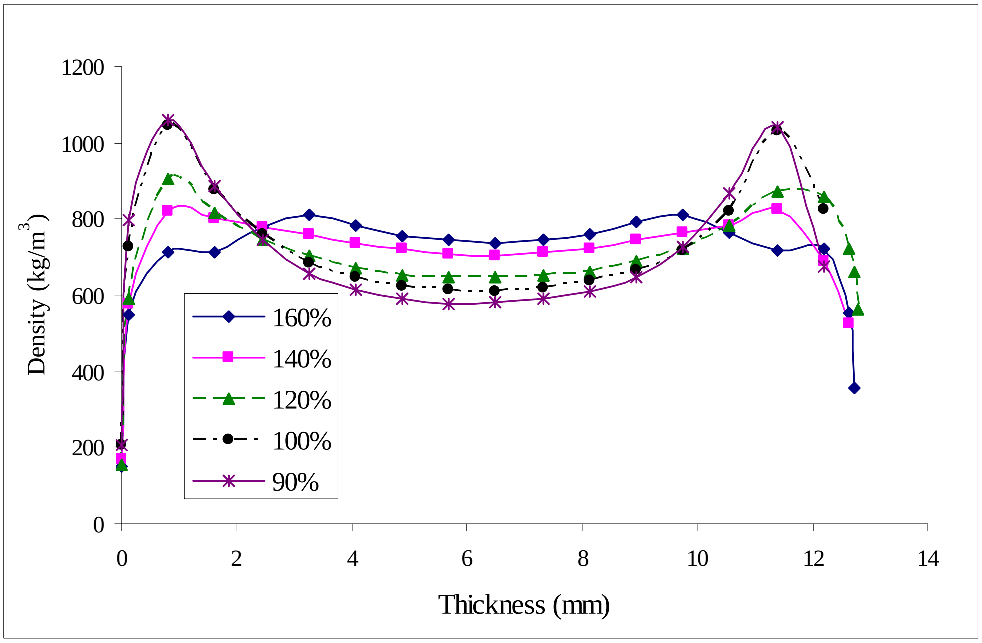

Figure 7. Density profiles with different initial platen positions (see Fig. 2 for legend definitions).

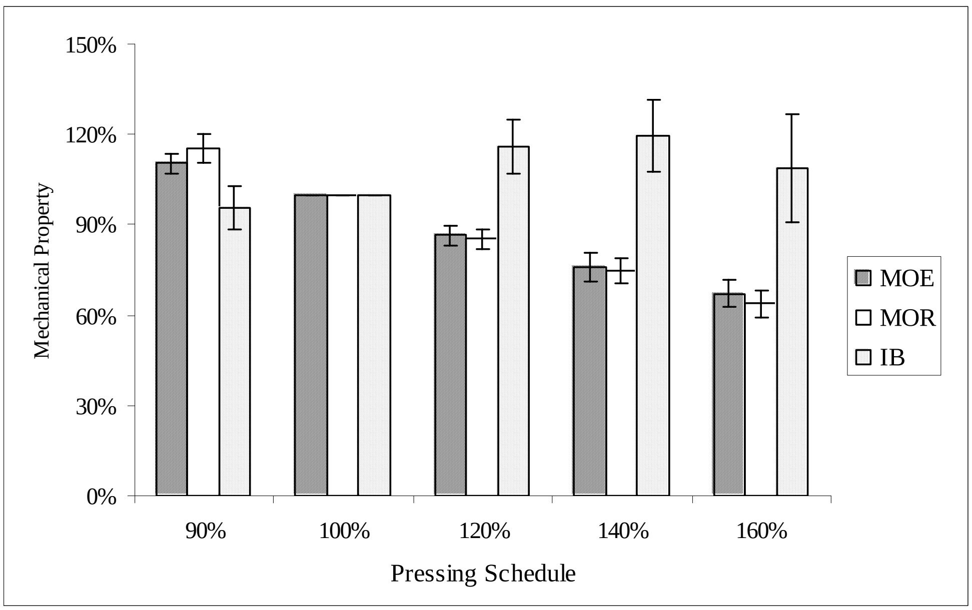

Figure 8. Mechanical properties with different pressing schedules.

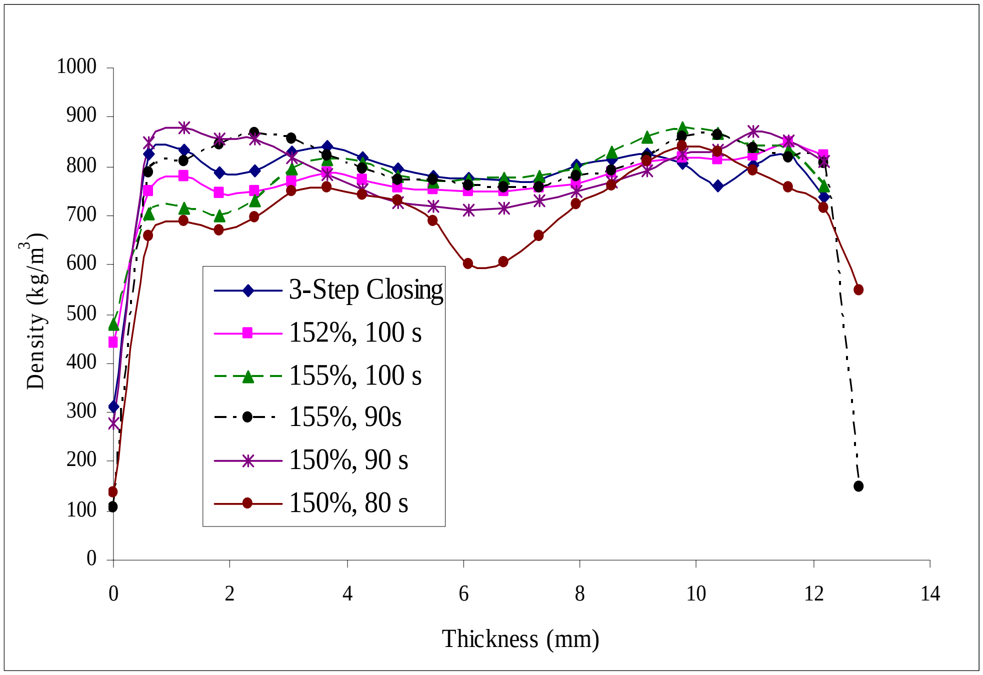

Figure 9. Density profile with different pressing strategies (see Fig. 1 for legend definitions).

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