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Phenol-Formaldehyde (PF) Resin Bonded Medium Density Fiberboard[*1]

Byung-Dae Park[*2] · Bernard Riedl[*2] and Sang-Jin Park[*3]

ABSTRACT

This study was conducted to manufacture MDF panels bonded with PF resins which provide excellent durability and dimensional stability with panels, and to identify benefits and weaknesses of using PF resins for MDF panels that have been manufactured with urea-formaldehyde (UF) resins for interior applications due to its low dimensional stability under moisture conditions. The results showed that the performance of PF-bonded MDF panels satisfied the performance requirement. A six-cycle aging test also revealed that PF-bonded MDF panels had high durability. Thickness swelling after 24 hours submersion in cold water was less than 2 percent, showing good dimentioanl stability. The identified weaknesses of using PF resins were relatively high resin content and long hot-pressing time. An acceptable resin content appeared to be 8 percent which can increase the production cost of PF-bonded MDF panels. The hot-pressing time (7 minutes) used in this study is relatively long compared to that of UF-bonded MDF panels. This result also indicates that hot-pressing process has to be optimized to control various pressing variables.

Keywords : MDF, Phenol-formaldehyde resin, MOR, MOE, IB strength, thickness swelling.

- 요 약 -

본 연구는 통상적으로 중밀도 섬유판 제조에 사용되고있는 요소수지를 페놀수지로 대체함으로써 그 장단점을 찾아보기 위해 실행되었다. 페놀수지을 이용해 제조한 중밀도 섬유판의 성능은 표준 요건을 충족시켰으며 높은 내구성을 보였다. 아울러 24 시간 냉수 침적후 두께팽창은 2 퍼센트 이하로 낮게 나타났다. 요소수지를 페놀수지로 대체했을 경우 단점들은 비교적 높은 수지함량 (8% 섬유전건중량기준)과 긴 열압시간 (7 분)으로 판명되었다. 이러한 결과들은 페놀수지을 사용한 중밀도 섬유판제조시 열압공정의 최적화가 되어야함을 시사하였다.

1. Introduction

Medium density fiberboard (MDF) is a relatively new type of wood-base composite material with the density range of 640 - 800 kg/cm^3. This type of products are manufactured in a socalled dry process in thicknesses from 3 mm up to 30 mm by hot-pressing. The pro-

*1 Received March 13, 1998
*2 Department of Wood and Forest Sciences, Laval University, Ste-Foy, QC, G1K 7P4,Canada
*3 Department of Wood Engineering, Kyung-Pook National University, Tae-gu, Korea

duction of MDF panels is constantly expanding, and in May of 1996, the total North American capacity reached 2.1 million m^3 (3/4 inch thickness basis) (RISI, 1996). The global scarcity and the high cost of timber and plywood are stimulating the increase in MDF production. In addtion, typical features of MDF panels are good machinability comparable to solid wood, relative insensitivity with the quality of the raw material, moulding ability for wide variety of surface decorations, and smooth surface suitable for various surface finishings.

For the manufacture of MDF, refined wood fibers are reconsituted into panels with fibers bound together by synthetic adhesives through compression to its final thickness in a hot-press. Traditionally, MDF is manufactured using urea-formaldehyde (UF) resin as a binder to bond the wood fibers. In spite of its low cost and proven performance in wood panels, the poor durability and stability of UF bonded MDF limits its use to interior and non-structural applications such as furniture production and decorative panels. For example, these limitations have been studied by several researchers dealing strength losses, irreversible swelling of UF-bonded composite panels, and formaldehyde release (Gillespie, 1965; Gillespie and River, 1976; Myer, 1986).

By contrast, phenol-formaldehyde (PF) resin is classified as an exterior adhesive for plywood, particleboard and oriented strandboard (OSB). This is due to its resistance to water, weathering and high temperature. In addition, formaldehyde emission from PF resin bonded products is nearly non-exsistent (Emery, 1986). The use of PF resin in MDF would provide high durability and stability.

However, several attempts of using PF resin for MDF panels have been conducted. Chow (1979) prepared PF resin bonded MDF panels from red oak sawdust fibers with a press temperature and time of 180℃ and 9 minutes. He found that a 6.5 percent resin level had acceptable strength properties for three-layer MDF panels. Employing various processing conditions including three resin levels, three press temperatures, and three mat moisture contents, Chow and Zhao (1992) also prepared MDF panels from mixed wood residues using a 8 percent level of PF resin. They reported that mat moisture content plays an important role in influencing all properties. Apart from the above two studies, there has been no systematic approach to use PF resin for MDF panels.

Traditionally, the two drawbacks that have prevented wide use of PF resins in the manufacture of particleboard and MDF have been resin cost and cure speed. Resin cost would increase about twice if phenolic resins replaced UF resin on weight basis, and the press cycle would have to be extended by 50-75 percent (Graves, 1993). To be cost effective with UF resin being used at 10 percent level, the resin content of PF resin should be reduced to half of the UF resin level (i.e., 5 percent). But, about 6 or 7 percent of PF resin level could be considered as a compromise if PF-bonded MDF panels have high durability and stability. In addition, the cure speed of PF resin also should be improved to the range of UF-bonded MDF panels. The slow curing of PF resins can be enhanced through cure acceleration using varoius additives.

A study has been initiated with the ultimate goal of developing an exterior grade MDF panel bonded with a cure accelerated PF resin. As part of the study, this work was conducted to identify advantages and weakness of using PF resins in making MDF panels.Therefore, this paper reports the preliminary results of MDF performance made of using two commercial PF resins and one laboratory synthesized PF resin

2. Materials and experimental methods

2.1. Resin synthesis

Two PF resins were used and referred to as PF A and B, respectivley. For comparison, a laboratory PF resin (PF C) was synthesized according to the following two-step procedure consisting of both a non-resinous mthylolated phenol condensate (part one) and a highly condensed PF resin (part two) (Chiu, 1984).

For part one, the rector was charged with phenol (90%), paraformaldehyde (45.6%), and water. After heating the components to 40℃ in the reactor, the initial addition of sodium hydroxide (50%) was slowly added over 10 min. When the temperature rose to 100℃, the resin was cooked for 2 - 3 min. and then cooled to 65℃ where it was cooked for 65 min. The temperature was held at 65℃ until the Gardner-Holdt viscosity ranking (25℃) was AB. The resin was then cooled to 40 - 30℃, and the second portion of sodium hydroxide (50%) and amonium hydoxide (28 - 30%) were added.

The second part of the preparation followed similar procedure to part one with charging phenol (90%), formaldehyde solution (41.5%), and water into the reactor. After the temperature reached 40℃, the initial amount of sodium hydroxide (50%) was slowly added over a 10 - 15 min. period and the temperature was allowed to rise to 95℃ as quickly as possible. The resin was cooked at 95℃ to a Gardner-Holdt viscosity ranking (25℃) of AB, and then cooled to 80℃. The temperature was held at 80℃ until the viscosity ranking (25℃) was KL. Ten minutes later, the resin was colled to 40 -30℃, and the second portion of sodium hydroxide (50% sol.) and amonium hydroxide (28 -30 %) were added.

The two parts of the resin prepared separately were mixed together in a 1:1 (V/V) ratio for a target solids content of 61 %. which yielded pan solids of 50.8 - 53.0% (ASTM D 4426, 1993). The mixed PF resin is referred to as PF C.

2.2. MDF panel preparation

Commercial MDF fibers prepared by a pressurized refining process, predominately mixed hardwoods species. The fibers were dried to about 2 percent moisture content before being blended with resins. Liquid PF resins were sprayed at 345 kPa onto the dried fibers in a rotary drum blender. The resins were applied at 8 percent resin solids based on oven dry weight of the furnish. Before resin application, an emulsified wax for UF and slack wax for PF resins were applied at a 1 percent (% wt based on oven dry weight of the fiber) onto the furnish in the same blender. A pumping system in conjuction with a pressurized atomizing air stream was used to deliver and atomize the wax and resin, respectively.

The dried fibers were felted into a mat of 50.8 cm by 61 cm (20 by 24 in.) with a target density of 780 kg/m3 using a fiber felting machine. Two mats prepared were prepressed and put together to form a single mat. The fiber mat were hot-pressed at 205℃ for 7 minutes. The initial pressure was allowed to incease to 4.5 MPa (655 psi). After aproximately 15 seconds, the pressure was reduced to 3.8 MPa (546 psi) and maintained for 3.75 minutes. The pressure was further decreased to 2.3 MPa (328 psi) and maintained 2.5 minutes. The pressure was completely released over the last 30 seconds.

2.3. Panel testing

The mechanical properties of prepared MDF panels included dry static bending (modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond (IB)), and wet MOR after the accelerated aging by the six-cycle test (ASTM D-1037, 1991). Two MDF panels were prepared for each type of the resin used. From these boards, nine specimens were cut for IB tests and eight specimens for MOR and MOE. Four

MOR specimens were tested dry and four after accelerated aging by the six-cycle method. Thickness swelling was also measured by soaking three MDF panels in cold water (20℃) for 24 hours.

3. Result and Discussion

MOR is an important property determining the applicability of wood composite boards for structral components. Fig. 1 shows the MOR of MDF panels bonded with different PF resins. The PF C resin bonded MDF had 45.6 MPa, showing the highest MOR following PF B and A with 43.8 and 37.7 MPa, respectively. These MOR are above the acceptable requirement specified ANSI A208.2 (1994) which is 34.5 MPa. After the six-cycle accelerated aging test, both PF-A and -B bonded panels retained more than 80% of dry MOR, which is also above the requirement.

During the six-cycle aging procedures, most of MDF panels retained their shape with sligthly swollen thickness. This result indicates that the use of PF resin provides good dimensional stability with MDF panels compared to UF resin-bonded MDF. In general, UF resin-bonded MDF panel experience severe thickness swelling and even delamination when immersed in water (Gillespie and River, 1976). In addition, Fig. 1 also indicates that the quality of PF-bonded panels depends on the specific PF resin used.

MOE is also an important property beacuse it is a measure of the stiffness, or resistance to bending. The MOE results for the panels are shown in Fig. 2. Regardless of the resin types, all panels have higher MOE values than the ANSI requirement which is 3,450 MPa. The MOE values of all PF-bonded panels were close each other. After the accelerated aging test, the MOE values of PF B-bonded MDF panels showed much greater dimensional stability than that of PF-A bonded panel.

Internal bond (IB) strengths, or tensile strength perpendicular to the board surface is a widely determined property in most of wood-based composite panels. The IB strengths of the panels are presented in Fig. 3. IB strengths of PF-A bonded MDF panels just satisfied the

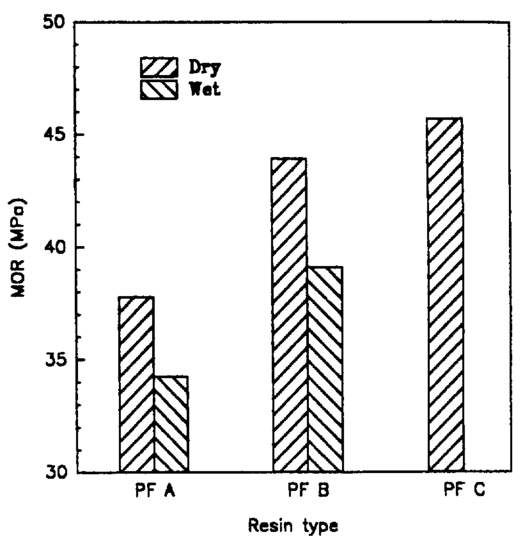

Fig. 1. Dry and wet MOR of PF-bonded MDF panels.

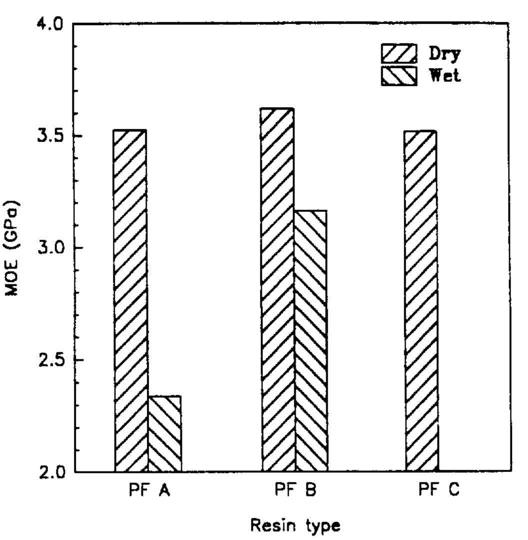

Fig. 2. Dry and wet MOE of PF-bonded MDF panels.

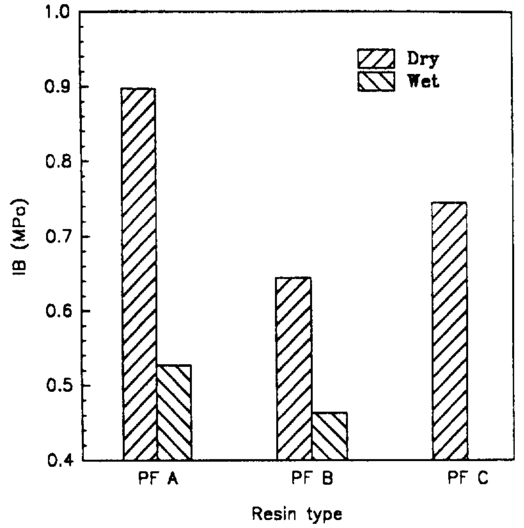

Fig. 3. Dry and wet IB of PF-bonded MDF panels.

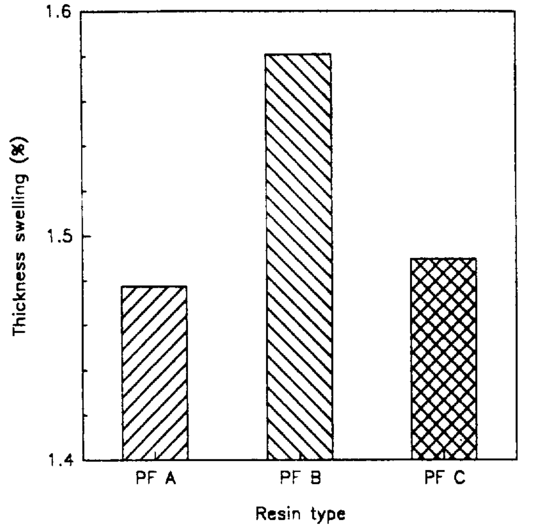

Fig. 4. Thickness swelling of PF-bonded MDF panels.

standard requirement which is 0.9 MPa. Both PF-B and -C resin bonded MDF panels did not satisfy the minimum level. This might be attributed to the specific resin formulations of PF-B and -C resins, which influences the resin distribution on woof-fiber surfaces. Another possible reason might be long curing time needed for PF resin. However, the aged samples after the six-cycle aging retained more than 50 percent of the dry IB values. This result suggest that a specific PF resin formulation be tailored to meet the panel performance requirement. As shown in both MOR and MOE, the use of PF resin could benefit from better dimensional stability of MDF panels.

Fig. 4 shows thickness swelling of MDF panels after submersion in cold water for 24 hours. PF-B bonded-MDF panels showed the largest thickness swelling (about 1.58%) followed by PF-C and PF-A bonded MDF. However, all MDF panels bonded with the three PF resins showed very low thickness swelling; less than 2 percent. Compared to other wood composite products such as UF resin bonded-MDF, particleboard, and OSB, this result is a quite encouraging feature. For example, the thickness swelling of OSB (greater than 12.7 mm in thickness) is 10 percent (CSA 0437-93, 1993). The thickness swelling showed a reversed relationship with the IB strength. The lower IB strength of MDF panels, the larger thickness swelling of the panels. This might be due to adhesive strength of PF resin in the panel core where temperature is lower than that of the panel surface. A good adhesion between fibers gives a high IB strength which will eventually reduces the thickness swelling of the panel.

Results in Fig. 1 to 4 satisfied the minimum requirements for MDF performance in terms of bending properties, and clearly indicate that the use of PF resin gives good dimensional stability to MDF panels. However, the IB requirement was partially met by the required minimum level. Thus, PF resin formulation should be refined and the resin distribution should be improved. In addition, hot-pressing conditions such as pressing temperature, closing time to reach final board thickness, and the platen position affect vertical density profiles of final MDF panels. The optimization of these conditions could modify the density profiles to improve IB strength of PF bonded-MDF panels.

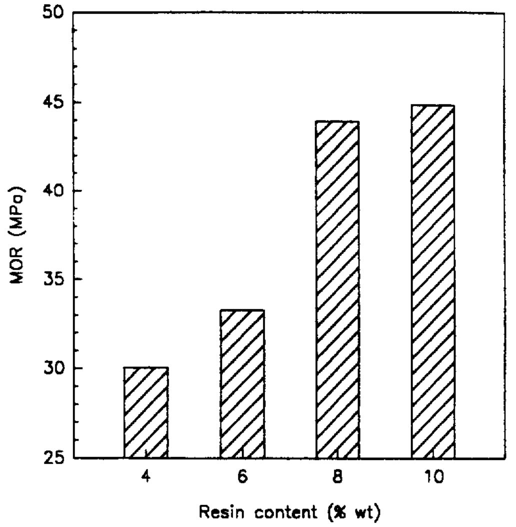

Fig. 5. MOR of PF-bonded MDF panels with different resin contents.

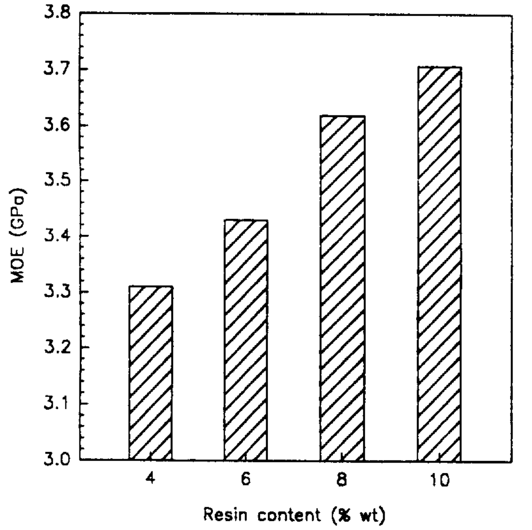

Fig. 6. MOE of PF-bonded MDF panels with different resin contents.

With improved dimensional stability and durability, PF resin bonded MDF panel might be used in exterior applications.

As mentioned, one difficulty in using PF resin for MDF panels is its cost which is almost double that of the UF resin. Currently, UF resin is being used at a level of about 10 percent based on oven dry weight of furnish. In order for PF resin to be competitive with UF resins in terms of resin cost, the resin content should be reduced as low as the half of UF resin content. For this purpose, PF-B resin was selected to evaluate the effect of resin content on MDF properties.

Fig. 5 shows the dependence of MOR values of MDF on the resin content. The MOR values increased with increasing resin content from 4 percent to 10 percent. The MOR decreased significantly below 8 percent resin content, and the resin contents of 4 and 6 percent did not satisfy the MOR limit required by the standard. This results shows that the 8 percent resin content is acceptable level in terms of MOR with this type of resin.

Fig. 6 shows the effects of resin content on

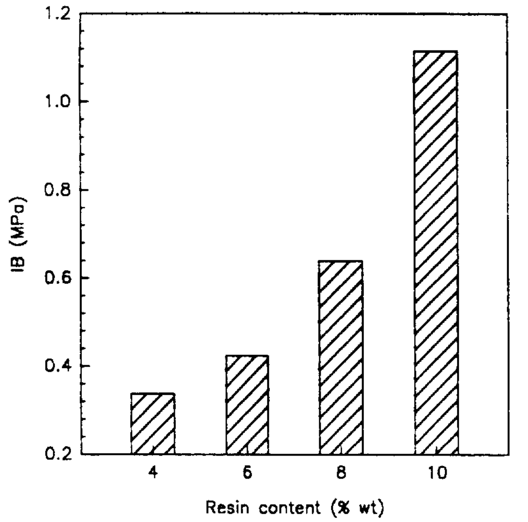

Fig. 7. IB strength of PF-bonded MDF panels with different resin contents.

the MOE of MDF panels. As expected, the MOEalso increased with rising in resin content. The MOE values changed from 3310 MPa to 3707 MPa when the resin content increased from 4 percent to 10 percent. Above 6 percent resin content, the minimum MOE level of the standard was staisfied while 4 percent level was below the minimum.

Fig. 7 illsstrates the dependence of IB on the resin content. As expected, the IB also improved with increasing the resin content. The IB value of the 10 percent resin content satisfied the requirement of the MDF standard. Below 10 percent resin content, IB values were less than that of the standard (0.9 MPa).

From the above results, all MOR and MOE values of different resin contents satisfied the standard requirements. The result indicates that the optimum resin content based on this study appeared to be 8 percent. But, the IB values below 10 percent resin content were below the requirement. The above result showed that IB value is a critical factor for selecting a optimum resin content of MDF panels. This could be done by either improving resin distribution, resin reaction rate, or optimizing hot-pressing conditions that affect both the curing behavior of resin and the vertical density profiles of panel. However, these resin contents of either 8, or 10 percent should be reduced further in order to be cost effective with UF resin.

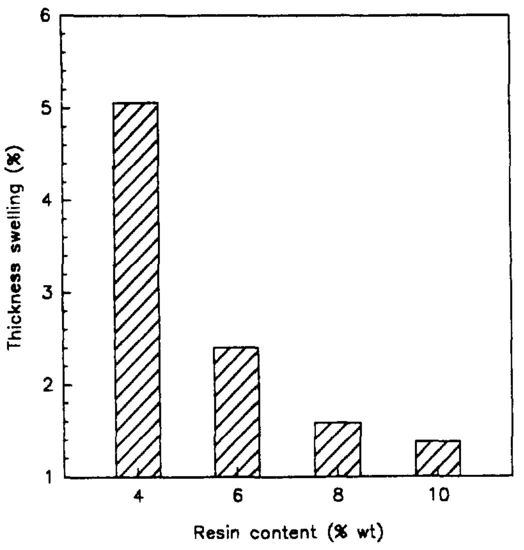

Fig. 8. Thickness swelling of PF-bonded MDF with different resin contents.

Fig. 8 shows thickness swelling of the panels bonded with UF and PF resins after 24 hour soaking in cold water. As expected, the thickness swelling of MDF panels bonded with PF resin decreased with increasing the resin content. This is exactly the opposite trend to the IB strength as a function of the resin content. This result is quite similar to the previous one (Fig. 3 and 4). In general, the thickness swelling is quite small for all resin contents used. Even the lowest resin content (4 %) level showed just 5 percent thickness swelling.

4. Summary

The PF resin bonded-MDF panel produced statisfactory bending properties (MOR and MOE). However, the IB strength should be improved to meet the minimum level of the standard. The six-cycle accelerated aging test proved that PF-bonded MDF panels were dimensionally stable and durable. The optimum resin content appeared to be 8 percent which should be further reduced to be cost-effective to UF resin bonded-MDF panels. The results showed that the use of PF resin provided a good dimensional stability with MDF panels. However, two major weaknesses in the use of PF resin for making MDF were identified; relatively high resin content and long hot-press time. High resin content has to be reduced through a good resin distribution system. Better dimensional stability could be compromised with relatively high PF resin content. A fast-curing PF resin system could reduce long press time. Also, the hot-pressing process should be optimized for a specific PF resin to manipulate both the curing behavior of PF resin and the vertical density profile of panels.

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