PROPERTY COMPARISONS AND BONDING EFFICIENCY OF UF AND PMDI BONDED PARTICLEBOARDS AS AFFECTED BY KEY PROCESS VARIABLES

Antonios N. Papadopoulos

The purpose of this paper was to compare physical properties of conventional particleboard bonded with amounts of UF and PMDI resin and to examine the effect of mat moisture content (MC), wax content and platen temperature on their bonding efficiency, as determined by internal bond strength. It was found that PMDI not only gave superior board properties compared with the UF, but the amount required was reduced considerably as well. The MC of the mat and the platen temperature did not significantly affect the bonding efficiency of PMDI bonded boards, but the bonding efficiency of UF bonded boards. The inclusion of 1% wax significantly affected the bonding efficiency of both resins, however the loss in strength was higher in UF than in PMDI bonded boards.

Keywords: Urea formaldehyde resin, Isocyanate resin, PMDI, Particleboard, Process variables, Wax, Mat moisture content, Platen temperature.

Contact information: Technological Educational Institute of Kavala, Branch of Drama, Department of Forestry and Management of Natural Environment, Laboratory of Wood and Wood Products, Drama, TK 66100, Greece. E-mail: antonios1974@hotmail.com, antpap@teikav.edu.gr

INTRODUCTION

Isocyanate resins, unlike urea formaldehyde (UF) resins which are normally soluble in water, are used either as a 100 percent solids content or in an emulsive form to which water and, or other additives may be added. Since they were first introduced to the German particleboard market in the early 1970s, the use of MDI (4,4'-methylenediphenyl isocyanate) binders in composite panels has grown significantly. When shipped to engineered wood products plants, MDI is a complex mixture of the isomers of di-, tri-isocyanates, and higher polymeric aromatic species derived from side reactions and generally sold as PMDI (polymeric MDI).

The purpose of this paper was two-fold:

i. To compare physical properties of conventional particleboard bonded with varying amounts of UF and PMDI resin,

ii. To examine the effect of mat moisture content (MC), wax content, and platen temperature on their bonding efficiency, as determined by internal bond strength.

This is the first study, as far as the author is aware, where these issues are addressed under identical manufactured conditions.

EXPERIMENTAL

Industrially produced wood chip furnish, comprising predominantly mixed softwoods (pine and fir) was used in this study. After screening (through a mesh with 5 mm apertures to remove oversize particles and then through a mesh with 1 mm apertures to remove undersize particles), the chips for the manufacture of UF bonded boards were dried to 2.5-3% moisture content (MC), while the chips for the isocyanate bonded boards were dried to 6.5-7% MC. It is known, in the latter case, that a higher mat MC can be tolerated (Deppe, 1977). The resins used for the manufacture of boards were UF (62.4% solids) and PMDI 100% solids. The water-repelling agent was an emulsifiable slack wax (E538) having 60% solids content. The amount of resin and wax used was based on the oven-dry weight of wood. A 2% aqueous solution of ammonium chloride (20% solids content), based on resin solids, was added to the UF as a hardener before spraying. All resins were applied to the furnish with a pneumatic atomising nozzle in a rotary drum blender. The order of spraying was wax, resin, followed by water to bring the mat to the correct moisture level.

Circular mats were randomly hand-formed on a circular aluminum caul. Mats were pressed without stops (10 mm/min), in a 30cm diameter electrically heated hot press for 3 min. Target board density was 650 Kg/m^3 and target board thickness 12.15 mm for all boards. Three replicates of each board were made, giving a total of 66 boards. Complete process information of the experimental design is in Table 1.

Boards were conditioned at 20^{o}C and 65% relative humidity prior to testing of internal bond strength (IB) (EN 319), modulus of rupture (MOR), modulus of elasticity (MOE) (EN310), and thickness swelling after 24hours immersion in water (TS) (EN317).

Table 1: Experimental design.

Variables	Constants
UF 7, 10, 13% PMDI 2, 4, 6%	Mat MC 10% Press temperature 180 ^{0}C Press time 3 min
Mat M.C 7, 10, 13 % UF 10% PMDI 4%	Press temperature 180 ^{0}C Press time 3 min Wax 1%
Press temperature 170, 180, 190^{0}C UF 10% PMDI 4%	Mat M.C 10% Press time 3 min Wax 1%
Wax 0 ,0.5 ,1 , 1.5% UF 10% PMDI 4%	Mat M.C 10% Press temperature 180 ^{0}C Press time 3 min

RESULTS AND DISCUSSION

Effect of Resin Type

Mechanical properties

The effect of resin type on bonding (IB) and bending properties (MOR, MOE) is shown in figures 1,2 and 3 respectively. From these, it can be seen that in order to provide equivalent board mechanical properties using UF and PMDI, it is possible to use PMDI resin at a considerable lower dosage. For example, it can be seen from figure 1 that UF bonded boards required 7% resin to achieve an IB of 0.68 N/mm^2, while 2.8% PMDI was needed. This represents reductions in dosage of 60%. However, this tendency was reduced to 37.5% at higher resin levels, since UF bonded boards required 9.6% to achieve an IB of 1.01 N/mm^2, while 6% PMDI was needed. With regard to MOR, UF bonded boards required 7% resin to achieve a value of 13.1 N/mm^2, while 2.5% PMDI was needed (see fig.2). This represents a reduction in dosage of 64.2%. This tendency remained the same at higher resin levels, since UF bonded boards required 13% to achieve a MOR of 1.01 N/mm^2, while 4.5% PMDI was needed (reductions in dosage of 65.3%). Modulus of elasticity showed similar trends to MOR. The results are broadly in line with those reported by Adams (1980) and Frink and Layten (1985). According to the former study the isocyanate dosage can be reduced to about one quarter of the requisite UF dosage to achieve equivalent board properties, whereas in the later study an approximate binder reduction by a factor of about 60 is suggested.

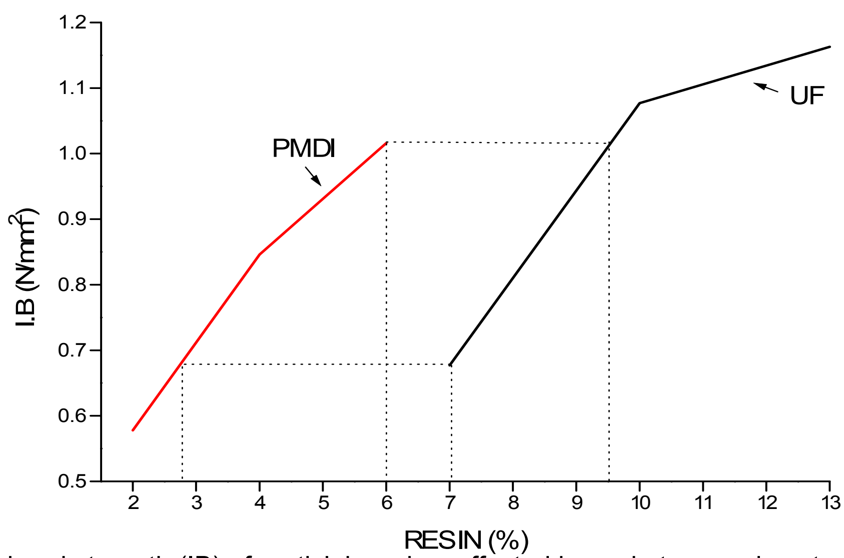

Fig. 1. Internal bond strength (IB) of particleboard as affected by resin type and content. Dashed lines indicate equivalent board property levels for comparisons.

Dimensional stability

The effect of resin type on 24 hours thickness swelling (TS) is shown in figure 4. In order to provide equivalent board dimensional stability using UF and isocyanate resins, it is possible to use isocyanate resin at a lower dosage. For example, an amount of 7.5% UF resin resulted in a thickness swelling of 28.6%, whereas the same level of thickness swelling was obtained at a much lower amount of PMDI (2%). This tendency remained the same at higher resin levels, since UF bonded boards required 13% resin to achieve a 20.95% TS, while 3% PMDI was needed (reductions in dosage of 76.2%).

From the above discussion, is clear that that in order to provide equivalent board properties using UF and PMDI resin, it is possible to use PMDI at a considerable lower dosage. This can be attributed to the way that the resins form bonds with wood surfaces.

Unlike formaldehyde resins, which bond by mechanical means (H-bond), isocyanate resins form covalent bonds with wood surfaces. A covalent bond has an energy in the range of 70-100 kcal per mole, while an H-bond, the type most normally associated with adhesion, is in the range of 5-10 kcal per mole. Technically, the reaction is characterized as an addition reaction, which yields a cross-linked, substituted urea and carbon dioxide (Deppe, 1977).

Another possible explanation for the superior performance of isocyanate resins is related to their high mobility on the wood surface. One reason for this, is their self-activated flow; when isocyanate droplets are placed on the wood surface they spread out spontaneously without the need of any external forces. This high mobility, according to Roll (1997), causes penetration to considerable depth into compressed particles, which can result in their total impregnation. This penetration may repair weak zones (chips in particleboard usually damaged by cracks and fissures) by sticking them together.

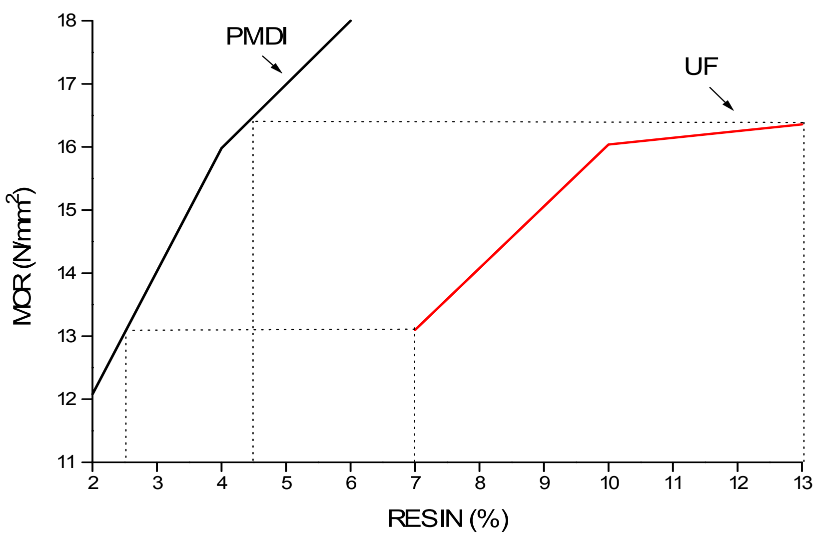

Fig. 2. Modulus of rupture (MOR) of particleboard as affected by resin type and content. Dashed lines indicate equivalent board property levels for comparisons.

Effect of Mat Moisture Content on Bonding Efficiency

The IB data at various mat moisture contents are shown in Table 2. From this, it can be seen that the bonding efficiency of UF resin was strongly influenced by the mat MC. Thus, the values at 10% MC were significantly higher than those developed at 7 or 13%, however between 7 and 13% there was no significant difference. The significant difference between 7 and 10% MC can be attributed to the fact that at 7% MC, the wood-glue interface was adequate for good glue bond formation (enough water to obtain sufficient hardening of the UF molecule), but the wood was not plasticised sufficiently for the maximum number of bonds to be formed, as evidenced by the failure of IB samples in the surface layers. Plastization of wood occurs when wood is heated at about 180^o (as in this study), however the low pressing time was a limited factor. The explanation for the significant difference between MC's of 10 and 13%, was due to the excess amount of moisture at the 13% level, particularly in the centre of board as the press cycle proceeded, which reduced optimum conditions for glue bond formation, since water molecules act as a competitor in the formation of hydrogen bonds between the UF resin and the wood chips.

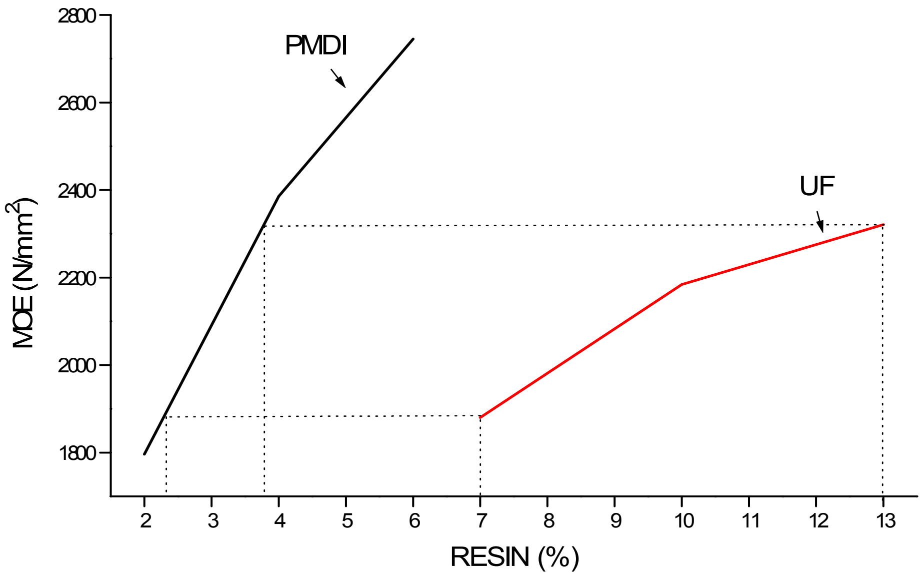

Fig. 3. Modulus of elasticity (MOE) of particleboard as affected by resin type and content. Dashed lines indicate equivalent board property levels for comparisons.

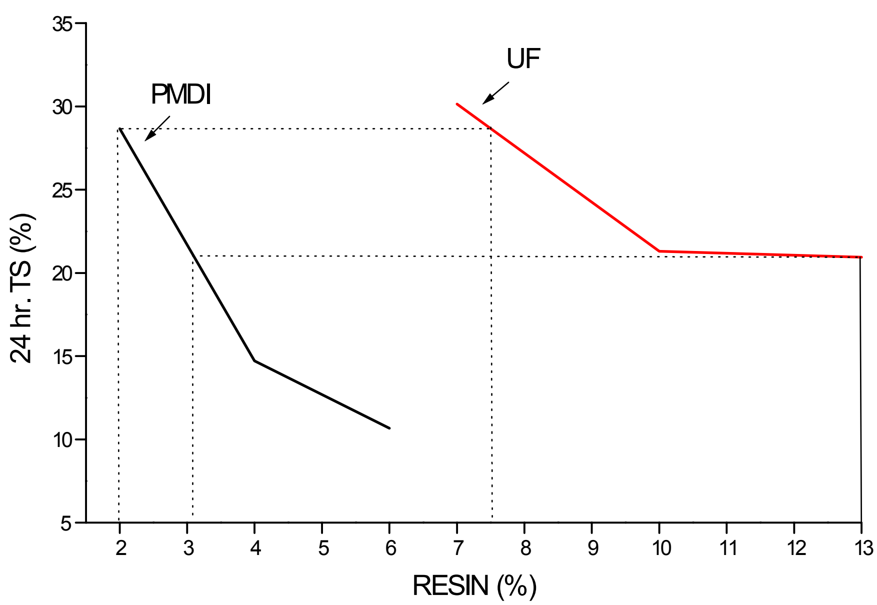

Fig. 4. Thickness swelling (TS) of particleboard as affected by resin type and content. Dashed lines indicate equivalent board property levels for comparisons.

The MC of the mat did not significantly affect the bonding efficiency of PMDI resin, indicating that isocyanate resins can be used at MC higher than those permitted for the aldehyde-based resins. This is due to the direct bonding between the resin and the wood surfaces. The results presented in this paper are in line with those reported by Deppe (1977) and Udvardy (1979), but they were not consistent with those reported by Johns et al. (1982). In the latter case a significant reduction of IB was observed when the MC of the mat was greater than 12%.

Effect of Platen Temperature on Bonding Efficiency

The IB data at various platen temperatures are shown in Table 2. From this, it can be seen that higher platen temperatures resulted in improved IB. This positive influence can be explained in terms of the amount of heat in the mattress, and in particular the core, when exposed to elevated temperatures. Because the core of the mattress is always at the lowest temperature compared to the surfaces, the platen temperature should be such to ensure that the core reaches a sufficiently high temperature to allow the resin to cure. Increased temperature will promote increased cross-linking and curing of the resin, in addition to improved plastization of wood, and hence improved those properties such as IB, which are particularly sensitive to bond quality.

From the Table 2, it can be also seen that the bonding efficiency of PMDI resin was not significantly affected by the platen temperature, whereas the bonding efficiency of UF bonded boards was significantly improved when the temperature was raised to 190°C.

Table 2: Internal bond strength (IB) of particleboard specimens. Values in parentheses represent the coefficient of variation (%). Different letters show which values are statistically different at the 5% level. (For process variables involved see Table 1).

Resin Type	Mat MC (%)	IB (N/mm^2)	Platen Temperature (°C)	IB (N/mm^2)	Wax (%)	IB (N/mm^2)
UF	7	0.689 A (8.8)	170	0.799 A (5.4)	0	1.077 A (8.7)
UF	10	0.828 B (7.8)	180	0.828 A (7.8)	0.5	0.929 AB (9.1)
UF	13	0.713 A (10)	190	0.912 B (9.8)	1	0.828 B (7.8)
PMDI	7	0.692 A (10.1)	170	0.681 A (11.1)	0	0.846 A (9.9)
PMDI	10	0.717 A (6.5)	180	0.717 A (6.5)	0.5	0.815 AB (6.7)
PMDI	13	0.731 A (8.4)	190	0.729 A (7.9)	1	0.717 B (6.5)

Effect of Wax Content on Bonding Efficiency

The IB data at various wax contents are shown in Table 2. From this, it can be seen that higher wax contents resulted in decreased IB. This suggests that the wax interfered with both UF and PMDI resin bonding during pressing, resulting in reduced bond quality. This reduction was significant above 0.5% wax, for boards bonded with either type of resin.

Although the performance of both resins was the same towards the wax content, the presence of wax was more detrimental in the boards bonded with UF, since an increase in wax content from 0 to 1% resulted in 30% reduction in IB, whilst the reduction in PMDI bonded boards was 18%. This might be due to differences in chemical bonding between UF and PMDI resins. The wax apparently interferes with UF resin when hydrogen bonds are formed, at least to a greater degree than in the case of covalent bonds of PMDI.

CONCLUSIONS

1. Compared with UF resin, PMDI resin had better bond strength for particleboard as determined by bending properties and internal bond.
2. Dimensional stability properties were also better for PMDI bonded board.
3. The MC of the mat and the platen temperature did not significantly affect the bonding efficiency of PMDI bonded boards, but the bonding efficiency of UF bonded boards were influenced.
4. The inclusion of 1% wax significantly affected the bonding efficiency of both resins, however the loss in strength was higher in UF than in PMDI bonded boards.

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