J Wood Sci (2006)
DOI 10.1007/s10086-005-0757-0

ORIGINAL ARTICLE

Gwo-Shyong Hwang · Eugene I-Chen Wang
Yu-Chang Su

Preparation of composite board using foil-laminated and plastic-laminated liquid packaging paperboard as raw materials

Received: March 18, 2005 / Accepted: August 17, 2005

Abstract We investigated the properties of composite board formed using base sheets of aluminum foil-laminated and polyethylene (PE) plastic-laminated liquid packaging paperboard (LP) as an alternative to recycling these items in wastepaper stream. Boards of different specific gravities ranging from 0.55 to 0.75 were made by pressing shredded LP blended with urea resin having resin content of 6%–10% at 180°C. Subsequently, we also prepared mixed particleboard [wood (WD) particles and LP mixed], three-layered particleboard (LP as the middle layer, WD in the upper and lower layers), and wood particleboard all having resin content of 10% and various specific gravities. Static bending and internal bonding strengths and thickness swelling of the specimens were determined to examine their properties. At the same specific gravity, the properties of LP particleboards were affected by their resin content. The modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond strength of the LP particleboards increased with increasing specific gravity of the boards at the same resin content, but thickness swelling of the LP particleboards showed the reverse trend. The average MOR of the LP particleboards approximated that of the mixed particleboards and was greater than those of the three-layered particleboards and wood particleboards. Internal bond strength and thickness swelling of the LP particleboards were smaller than those of the other particleboards. Based on the above observations, we deemed that LP can be made into composite boards with adequate properties either alone or mixed with wood particles.

Key words Wastepaper · Liquid packaging paperboard · Composite board · Particleboard

Introduction

In recent decades, overexploitation of forest resources by mankind in the pursuit of better living standards and to satisfy material needs have led to drastically reduced forest stocking and forestland area. Hence, in addition to effectively utilize the existing forest resources, nations of the world are also paying special attention to the recycling and reuse of wastepaper derived from forest resources.

Wastepaper utilization has a wide spectrum. In general, based on material forms, four categories can be discerned: (1) utilized in planar material forms; (2) utilized in fiber forms; (3) utilized in molecular forms; and (4) utilized as an energy source. Our attempt to use wastepaper to make composite board belongs to a domain straddling the planar and fiber forms. In the field of wastepaper utilization, there have been substantial research efforts directed toward making and development of composite boards by many forest product and paper scientists. Kyzysik et al.[1] mixed wastepaper fiber with different proportions of wood fiber, subjected portions of the mixture to acetylation, and then used 3% or 7% adhesive to prepare hardboards by a dry method. The hardboards were subjected to various tests. The results indicated that when resin content was raised from 3% to 7%, various properties were improved. Although acetylation improved water absorption, thickness, and linear swelling properties, it also lowered mechanical properties. Higher proportions of wastepaper fiber had adverse effects on the mechanical properties, water absorption, and thickness swelling of the hardboards. Takata et al.[2] studied the use of wastepaper to make fiberboards. They disintegrated the wastepaper fibers, applied ozone treatment to the fibers, and then made fiberboards from the material. Tests of static bending strength, internal bond strength, and thickness swelling after water absorption suggested that at 0.25% to 0.5% ozone doses, fiberboard properties were improved. Massijaya and Okuma[3] diced old newsprint and formed particleboards with densities of 0.50 to 0.90 g/cm^3 with a resin content of 10%. The results indicated that static bending strength and thickness swelling of the particleboards

G.-S. Hwang · E.I.-C. Wang (✉) · Y.-C. Su
Taiwan Forestry Research Institute, 53 Nanhai Rd., Taipei 100, Taiwan
Tel. +886-2-2332-6044; Fax +886-2-2303-7832
e-mail: iwang@serv.tfri.gov.tw

decreased markedly with increasing board density; the internal bond strength of the boards, however, was quite low. The water absorption rate and thickness swelling of the particleboards still required improvement. Chen and Liao[4] made particleboard using waste drink packaging paperboard. Their study found that the presence of polyethylene (PE) film and aluminum foil on the paperboard interfered with bonding with the urea–formaldehyde (UF) glue, and caused a lowering of particleboard strength; however, these laminates had the effect of preventing the particleboard from imbibing water. Zauscher et al.[5] developed a pulp extrusion process using low grade wastepaper pulps mixed with mill sludges to be extruded at ultrahigh consistency and formed fiber composites having mechanical properties comparable with those of medium-density fiberboard (MDF) or hardboard (HB). Adding cross-linking resin to the mixture could control the stiffness of the boards as well. Yang et al.[6] integrated wastepaper in the preparation of a fire retardant-treated fiberboard for use as interior finishing material. Laboratory-scale fiberboards with specific gravities of 0.8 and 1.0, containing 10%, 15%, and 20% (w/w of board weight) of fire retardant and composed of shredded waste newspapers and UF resin at 10% material weight were prepared. The bending modulus of rupture (MOR) increased as board density increased, and decreased as the fire retardant content increased. Mechanical properties were inferior to MDF and HB, but were significantly superior to gypsum board (GB) and insulation board. The boards achieved pertinent fire retardation requirements for interior finishing purposes. Grigoriou[7] prepared wastepaper and wood composite bonded with isocyanate adhesive. One-layer boards were made using various ratios of wastepaper flakes to wood particles in mixtures using waste newspaper, office paper, and magazine paper. Polymeric methylene diisocynate (PMDI) resin was applied at the three different levels of 5%, 8%, and 10%. Wastepaper flakes in boards enhanced their appearance but caused internal bond strength, screw-holding strength, and thickness swelling to deteriorate substantially along with increased wastepaper percentage, while the bending strength was only slightly affected. Higher resin content improved all properties of boards. It was deemed that newspaper was the most suitable for board making, and magazine paper the least appropriate.[7]

In the present study, we investigated the use of aluminum foil-laminated and plastic-laminated Liquid-Pak liquid packaging base paperboard (LP) sheet to prepare particleboards using urea–formaldehyde resin. The often heavily waxed liquid packaging paper, although made of high quality virgin fibers, is difficult to recycle as a papermaking fiber source because the plastic and aluminum lamination needs to be detached and disposed of. Various wet strength and wax additives in the items also contribute to difficulties in repulping and stickies problems. Thus, when waste beverage packs enter recycling streams, they often need to be sorted out as an independent category and subjected to different treatments than other wastepapers.

The purposes of our study were to find alternative means of utilizing such a resource and to examine the properties of panel products made from it. In the study we initially made particleboards from the LP base sheets with different adhesive content and specific gravities. Then we prepared particleboards by mixing particles of LP and wood in different structures. Subsequently, we conducted tests of static bending strength, internal bond strength, and thickness swelling to evaluate the effects of different adhesive contents, specific gravities, and structures on the particleboards.

Materials and methods

Materials

Aluminum-laminated and plastic-laminated liquid packaging board

We obtained base sheets of the LP boards having a thickness of 0.35 mm from a domestic beverage packaging supplier. The LP board was a paperboard made of virgin long fibers with an aluminum foil lamination on the inside and a polyethylene (PE) film lamination on the outside, which imparts liquid barrier properties to the board. The aluminum foil in turn was a three-layer composite of PE–aluminum–PE. The base sheets were shredded into 4-mm strips that were 32 mm in length. The paper strips were conditioned to 3% moisture content.

Wood particles

Wood particles were supplied by a particleboard plant in Taiwan. The material was derived from furniture manufacturing residues, and hence was composed of mixed hardwood species such as ramin, rubberwood, and oak, etc. The particle size distribution was: retained on 6-mesh, 2.8%; 10-mesh, 15.3%; 18-mesh, 22.6%; 24-mesh, 9.5%; 36-mesh, 26.3%; and fines, 23.5%. The moisture content (MC) of the wood particles was conditioned to 3%. The urea–formaldehyde resin used was obtained from a commercial supply, had a solid content of 65% ± 3%, with a hardener dose of 0.4%.

Preparation of particleboards

The preparatory conditions for the particleboards are shown in Table 1. In order to investigate the effect of resin content on the LP particleboard (LPPB), urea resin contents of 6%, 8%, and 10% were applied and the particleboards were pressed to 1-cm thickness and 30-cm square with designated specific gravities of 0.55, 0.65, and 0.75. In order to compare the effect of particle components and specific gravities on board properties, we also prepared wood particleboards (WDPB), mixed particleboards (MXPB), and three-layered particleboards (TLPB; with the upper and lower layer of wood particle and LP particle center) with 10% urea resin content and board dimensions that were the same as the LP particleboards. The MX and TL particleboards had LP and WD weight ratios of 1:1.

Table 1. Conditions of particleboard preparation

Composite type	Material	Resin content (%)	Specific gravity	Construction
LPPB[a]	LP	6, 8, 10	0.55~0.75	Single layer
MXPB	LP, WD	10	0.55~0.75	Single layer
TLPB	LP, WD	10	0.55~0.75	Triple layer
WDPB	WD	10	0.55~0.75	Single layer

PB, Particleboard; LP, aluminum and plastic-laminated liquid packaging base paperboard; WD, wood; MXPB, particleboard of mixed composition; TLPB, three-layered particleboard; WDPB, particleboard prepared from wood

[a] LPPB was constructed using LP base sheets

The particleboards were hot pressed at 180°C using a three-stage pressing scheme; the first stage was 30 kgf/cm^2 for 60 s, the second stage was 15 kgf/cm^2 for 90 s, and the third stage was 30 kgf/cm^2 for 30 s. Two boards were prepared for each of the above conditions, and from each board three test specimens were cut for evaluation of individual properties. Thus, six replications were carried out for each sample.

Tests of the particleboards

The tests for static bending, internal bond strength, and water absorption swelling were carried out in accordance with JIS A5908:2003 test methods. Specimens for the static bending test had dimensions of 5 cm in width and 20 cm in length, load was applied at the center of the 15-cm span (15 times the board thickness). Deformation rate during loading was 10 mm/min. In the internal bond test, each specimen (5 × 5 cm) was glued to a steel anvil and a tensile load parallel to the specimen surface was applied at a rate of 2 mm/min; the maximum tensile loading at the point of delamination was determined for each test specimen. In the water absorption swelling test, specimens of 5 × 5 cm were placed horizontally in a bath of water at 25° ± 1°C, with the top surface of the specimen held 3 cm below the surface of the water for a period of 24 h. A micro-meter caliper was used to determine the thickness before and after water immersion and to calculate the thickness swelling.

Results and discussion

Effects of resin content and specific gravities of the LP particleboards on board properties

LP particleboards of different resin contents and specific gravities were tested for modulus of rupture (MOR) and the results are shown in Figs. 1 and 2. Figure 1 shows the performance of static bending in relation to board specific gravity and resin content. The results show that under any approximate specific gravity range, the greater the resin content, the higher the MOR of the board is. This observation demonstrates the importance of adhesive to the strength properties of LP particleboards. Furthermore, Fig. 1 shows that under any resin content, the greater the specific gravity, the markedly greater the MOR of the board is.

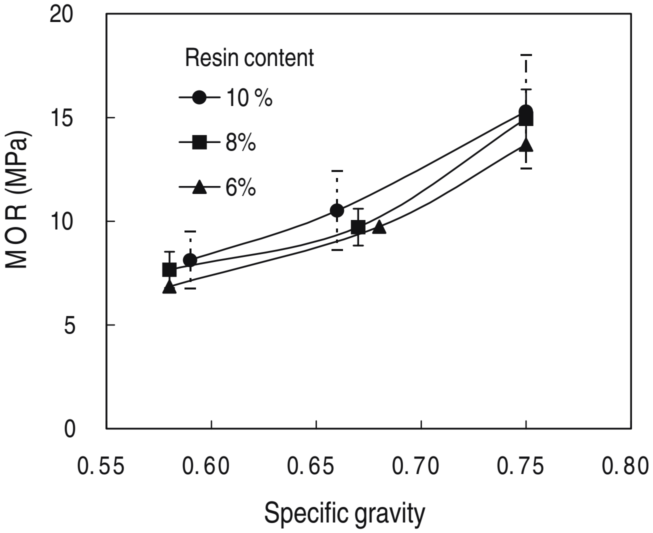

Fig. 1. Relationship between modulus of rupture (MOR) and specific gravity of particleboards prepared from aluminum and plastic-laminated liquid packaging base paperboard (LP) with different resin content

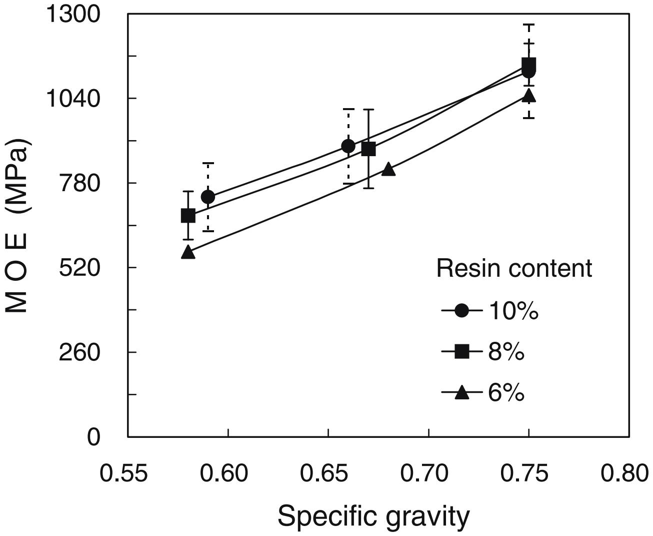

Fig. 2. Relationship between modulus of elasticity (MOE) and specific gravity of LP particleboards with different resin content

Also, the specific MOR increases markedly as board specific gravity increases. Thus, specific gravity of the LP particleboards has a notable influence on MOR values. For instance, at a resin content of 6%, when specific gravity of the LP particleboards increases from 0.58 to 0.75, the MOR increases from 6.86 to 13.73 MPa; doubling in strength. The static bending modulus of elasticity (MOE) performances of LP particleboards made with different resin contents in relation to board specific gravity are shown in Fig. 2. At any particular resin content, the static bending MOE increases markedly as specific gravity increases. In any approximate specific gravity range, the greater the resin contents of the board, the larger the MOE. Boards with resin contents of 8% and 10% showed similar MOE values, while boards with 6% resin content showed markedly lower MOE values. Furthermore, when the boards with different specific gravities, shown in Figs. 1 and 2, were tested with Duncan's multiple range test, the results suggested that for any particular resin content, the MOR and MOE values were significantly different at the 5% significance level.

Figure 3 shows the internal bond (IB) test results of LP particleboards having different board specific gravities and resin contents. The plot shows that at a particular resin content, the internal bond of LP particleboards increases markedly with increasing board specific gravity; the differences are all significant at the 5% level. In addition, at approximately the same specific gravity range, the IB of LP particleboard is greater for boards having greater resin content.

The thickness swelling values of the LP particleboards having different specific gravities and resin contents after 24 h of steeping in water are shown in Fig. 4. At any particular resin content, the thickness swellings of the LP particleboards decrease markedly along with increasing board specific gravities. Statistical analysis indicates that for the boards having 6% resin content, the differences are significant at the 5% level; and for the boards of 8% and 10% resin content, the differences are not significant. This is probably because the surface of the LP particles had intrinsic waterproofing treatment in their capacity as a liquid barrier; thus, when the particles are pressed tightly together, water seepage from the ends and lateral sides of the particles is reduced and the thickness is swelling lowered.[4,8] Figure 4 also shows that the thickness swelling of the LP particleboard is not distinctly influenced by the board resin content.

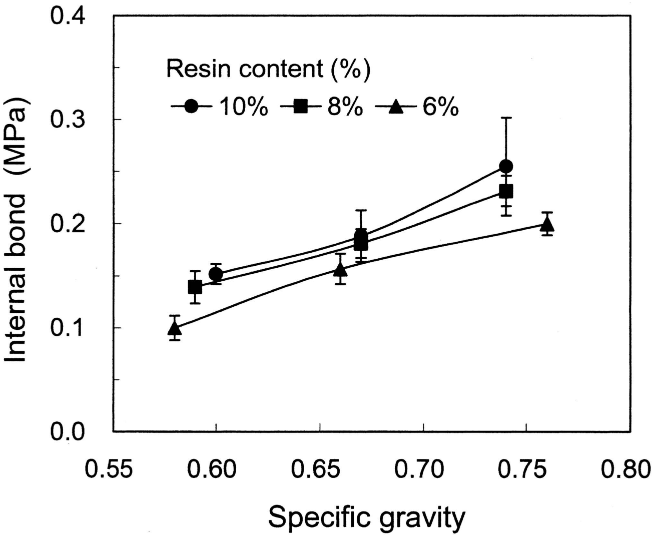

Fig. 3. Relationship between internal bond strength and specific gravity of LP particleboards with different resin content

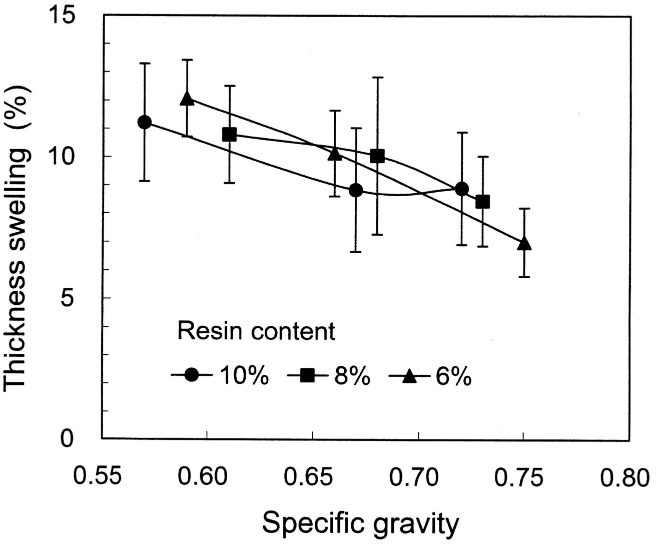

Fig. 4. Relationship between thickness swelling and specific gravity of LP particleboards with different resin contents after soaking in water for 24 h

Effects of particleboard specific gravity and construction on board properties

The results for the static bending performance of the four types of particleboard, i.e., LPPB, MXPB, TLPB, and WDPB, are shown in Figs. 5 and 6. Figures 5 and 6 indicate that particleboards of various constructions all show distinct increases in MOR and static bending MOE with increasing specific gravities of the boards. For LPPB, TLPB, and WDPB, different board specific gravities gave significant differences (5%) in MOR; whereas for boards of MXPB, there was no significant difference in MOR values. Figure 5 shows that when LPPB had a specific gravity of 0.75, its MOR was 15.3 MPa. In any specific gravity range, the LPPBs had MOR values that were superior to those of WDPBs. One possible reason is that the LP particles, with dimensions of 4 × 32 mm, are far larger than the average wood particles, and that the WDPB contains 50% fine wood particles (passing 36-mesh), which might lower the MOR with poorer overall particle integrity. At specific gravities of 0.65 and lower, the LPPBs have similar strengths to those of the corresponding WDPBs. TLPBs, although having the same composition as those of mixed LP-WD particleboards, have distinctly lower MOR values. At a specific gravity of 0.72, the TLPB has an MOR of only 7.55 MPa. It is possible that by placing the stiff LP layers on the outer

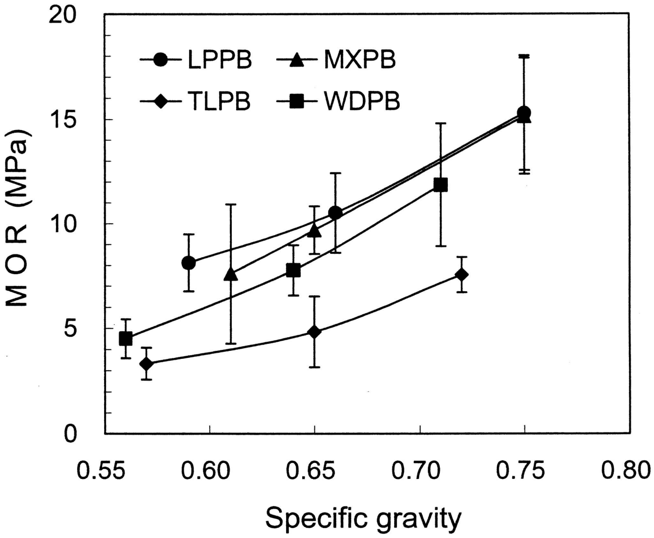

Fig. 5. Relationship between MOR and specific gravity of four kinds of particleboard for abbreviations see Table 1

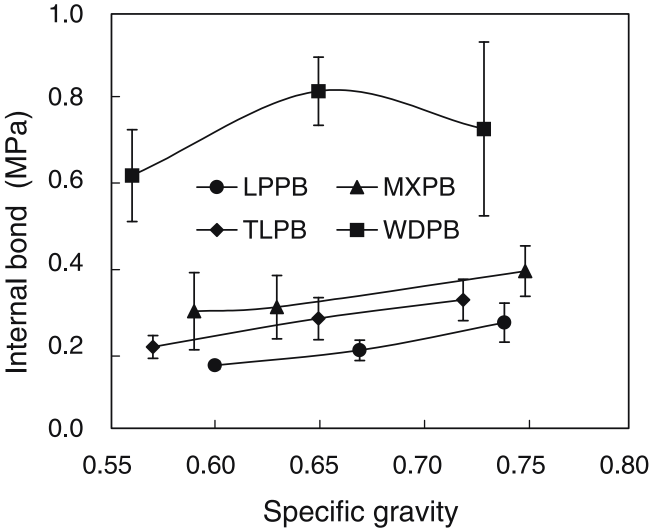

Fig. 7. Relationship between internal bond strength and specific gravity of four kinds of particleboard

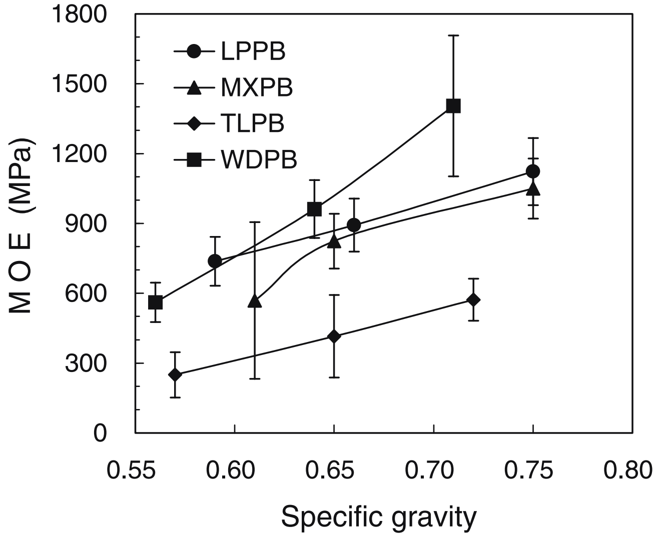

Fig. 6. Relationship between MOE and specific gravity of four kinds of particleboard

sides and the WD layer in the neutral plane, the resultant particleboard may have much improved performance. It is also quite possible that interface between layers of different materials can cause weak adhesion, resulting in lower overall strength of such constructions.

Figure 6 shows that at specific gravities of 0.65 or lower, the LPPBs have greater static bending MOE values than the corresponding MXPBs, whereas at specific gravities greater than 0.65, the reverse is true. In all specific gravity cases, the TLPBs have markedly lower static bending MOE values, similar to the MOR trend of Fig. 5, thus confirming the inferior construction of WD–LP–WD particleboards. There are significant differences (>5%) between the MOE values of LPPB and WDPB, but not for those of TLPB and MXPB.

Wood pulp made up about 75% LP material, together with 20% PE and about 5% aluminum foil. The virgin softwood fibers are mostly longer and stronger fibers that endow the products with good strength and toughness, as manifested in the MOR and static bending MOE values that were supperior to those of the other types of particleboards.

Figure 7 shows the relationships between the IB strengths of the four particleboard types and their specific gravities. Internal bond strengths tended to increase with increasing specific gravities for all board types. However, except LPPB, the boards show insignificant IB strength differences. The amplitudes of IB strength increases, however, are less than those of Figs. 5 and 6 for MOR and MOE. In all cases, WDPBs have IB that are significantly greater than the other three construction types. We suspect that the UF resin has a relatively poor bonding capacity with PE and aluminum films on the LP material, whereas it has good bonding with wood particles. The ranges of internal bond values for the particleboards are in the order: WDPB, 0.61–0.81 MPa; MXPB, 0.28–0.38 MPa; TLPB, 0.2–0.31 MPa; and LPPB, the poorest at 0.15–0.25 MPa.

The PE and aluminum foil laminations provide the LP particles with good water resistance, leading to the least thickness swelling among the various particleboard constructions. By the same token, the possibly lower wettability of the water-barrier materials caused LPPB to have inferior IB strength. We deem that this problem should be ameliorated with the use of different adhesives.

The results of 24 h of water immersion on board thickness swelling are shown in Fig. 8. Both WDPB and MXPB have a tendency to markedly increase thickness swelling with increasing board specific gravity. The nature of TLPB is unclear on this aspect, whereas the LPPB has lower thickness swelling with increasing specific gravity. In addition, at specific gravities greater than 0.60, the LPPB has lower thickness swelling than the other three types of particleboard. In general, boards with higher specific gravity are composed of greater amounts of materials, hence are sub-

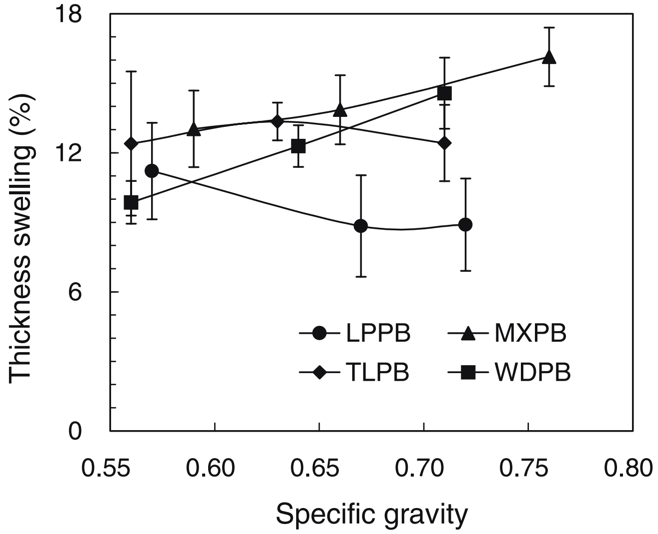

Fig. 8. Relationship between thickness swelling and specific gravity of four kinds of particleboard after soaking in water for 24h

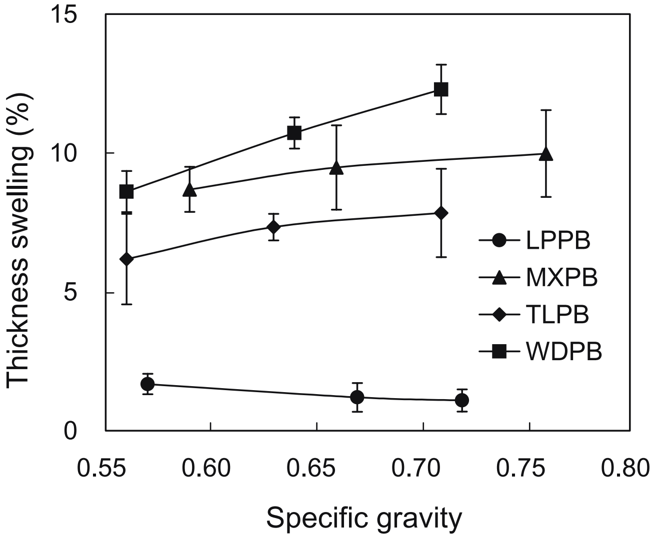

Fig. 9. Relationship between thickness swelling and specific gravity of four kinds of particleboard after soaking in water for 2h

jected to greater compression deformation during forming, which leads to greater expansion after water absorption. In the case of LPPB, however, the thickness swelling actually decreases with increasing board specific gravity. The probable reason for this is noted in the above paragraph.

In order to further understand the effects of waterproofing characteristics of the LPPBs on their thickness swelling, we also conducted a 2-h water immersion test for the four types of particleboard. The results are shown in Fig. 9. The plot shows that WD, MX, and TL particleboards have thickness swellings that increase with increasing board specific gravity, whereas the LP particleboards go the other way. Figure 9 also shows that the thickness swelling of LP particleboards is between 1.09% and 1.68%, which is much different from the values of 8.90%–11.21% for the same boards in the conditions of Fig. 8. If using the latter values as 100%, then after 2h of immersion, the LP particleboards have an average thickness swelling of only 13.7%. Similar comparisons between the two plots showed that the ratio of WDPB under the two conditions is 86.3%; MXPB has a ratio of 65.5%; and TLPB has a ratio of 56.0%. Thus, we can deduce that the waterproofing characteristics of the LP material cause the slow water uptake in the initial stage, which may be useful in lowering thickness swelling of particleboards that encounter brief water splashing in service conditions. In Figs. 8 and 9, except for WDPB, which has significant difference (>5%) in thickness swelling with different specific gravity, the particleboards have insignificant thickness swelling differences among different board specific gravities.

Conclusions

From the study using foil-laminated and plastic-laminated liquid packaging base sheets to prepare particleboard, we found that the MOR, static bending MOE, and IB strength of LP particleboard increased significantly with board specific gravity; whereas the thickness swelling of the LP particleboard tended to decrease with increasing board specific gravity. The option of making particleboard out of such raw material instead of putting it through the conventional pulp recycling route may present a potentially viable means of effectively utilizing such resources, particularly by using adhesives with better wetting capabilities than urea-formaldehyde.

Acknowledgments This study was successfully completed with the financial support of the Taiwan Forestry Research Institute, project nos. 92AS-8.2.3-F1-G1 and 93AS-8.2.3-F1-G1 (01). The authors are grateful for the support.

References

1. Krzysik AM, Youngquist JA, Rowell RM, Muehl JH, Chow P, Shook SR (1993) Feasibility of using recycled newspapers as a fiber source for dry-process hardboards. Forest Prod J 43:53–58
2. Takata S, Tominura Y, Hosoya S, Matsuda T (1994) Utilization of wastepaper (1). Fiberboard from wastepaper. Japan TAPPI J 48:1363–1369
3. Massijaya MY, Okuma M (1996) Development of boards made from waste newspapers. I. Production and fundamental properties of waste newspaper boards. Mokuzai Gakkaishi 42:1243–1249
4. Chen TY, Liao KH (1994) Particleboard made from used beverage cartons (in Chinese with English summary). Forest Prod Ind 13:611–624
5. Zauscher S, Scott CT, Willett JL, Klingenberg DJ (2000) Pulp extrusion for recycling wastepapers and paper mill sludges. TAPPI J 83:1–10
6. Yang HS, Kim DJ, Kim HJ (2002) Combustion and mechanical properties of fire-retardant treated wastepaper board for interior finishing material. J Fire Sci 20:505–517
7. Grigoriou AH (2003) Wastepaper–wood composites bonded with isocyanate. Wood Sci Technol 37:79–90
8. Nagata K (1988) The liquid packaging paperboard (in Japanese). In: Paper conversion handbook. Japan TAPPI. Tokyo, p 787