Research paper

Apply Single Image Multi-Processing Analysis Techniques to Evaluate Internal Bond Strength of Particleboard with Recycled Demolition Wood-Based Panels

Han-Chien Lin[1] Jin-Cherng Huang[2]

【**Abstract**】 This study was used planer-shaving particles of China fir (Cunninghamia lanceolata (Lamb.) Hook. var. lanceolata; China fir) and various commercial boards: polyvinyl chloride single-overlaid plywood (PVCOP), structural plywood with single spread of melamine resin coatings (MSP) and plywood with urea formaldehyde resin adhesive (UFP) as particles of the recycled demolition wood-based panels (RDWP). The particleboards for various mixture proportions of China fir/RDWP (100/0, 75/25, 50/50 and 25/75) with a nominal density were manufactured individually. The specimens were cut into 50 mm squares and then the internal bond strengths were tested. The designed method of the single image multi-processing analysis (SIMPA) including fade effective minus mode and fade effective plus mode was used for measuring the internal bonded areas in particleboard specimen. The wettability on these board surfaces of China fir and various boards was measured using contact angle meter. Both them were to evaluate the influence of mixture proportions of composed particles and the types of RDWP particles on bonded quality of particleboard. Results indicated that the more the mixture proportion of RDWP, the greater the internal bonded areas of RDWP and the smaller the internal bond strength. Moreover, using contact angle meter the results showed that the contact angle of board surface for China fir was 31.8°, PVCOP was 40.7°, MSP 52.1° and UFP was 41.1°. It is suggested that the more the mixture proportion of RDWP, the less the bond quality and the lower the internal bond strength obtained. Using the SIMPA to measure the internal bonded areas combined with contact angle measurements could provide an experimental data for referencing the internal bond state of RDWP particleboards.

【**Key words**】Single image multi-processing analysis (SIMPA) techniques, Recycled demolition wood-based panels (RDWP), Particleboard, Internal bond (IB) strength, Internal bonded areas, Contact angle.

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研究報告

應用單一影像多層分析技術評估解體材粒片板之內聚強度

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【摘要】本研究係以杉木（*Cunninghamia lanceolata*（Lamb.） Hook. var. *lanceolata*; China fir） 粒片與各種商用合板（聚氯乙烯合成皮單面貼面合板、三聚氰胺樹脂單面處理塗裝之構造用合板及尿素膠製成之合板）經搗切作爲解體材之粒片，分別依 100/0，75/25，50/50 及 25/75 等混合比製成相同密度之解體材粒片板，並切製成 5 × 5 cm 試片，經由測定內聚強度後，使用自行設計之單一影像多層分析技術（single image multi-processing analysis, SIMPA: 含 fade effective minus mode and fade effective plus mode）評估粒片板於破壞面之杉木及解體材內部膠合面積（internal bonded areas），並以接觸角儀測定杉木及視爲解體材各合板表面之接觸角作對照，藉以分析解體材粒片板所組成粒片種類及混合比對內聚強度之影響。試驗結果顯示，所製成之粒片板中含較多解體材比者，經由 SIMPA 技術得知其膠合面積較多，內聚強度較低，而較少者，則得到相反結果。另從杉木及各合板之接觸角試驗得知，杉木表面者爲 31.8° ，聚氯乙烯合成皮單面貼面合板者爲 40.7° ，三聚氰胺樹脂單面處理塗裝之構造用合板者爲 52.1° ，尿素膠製成之合板者爲 41.1° ，並知混合解體材比較多者，佈膠製板後之膠合性較差，故其內聚強度較低。因此應用 SIMPA 技術及表面濕潤角試驗，能有效評估解體材粒片板破壞面之內部膠合面積大小與其膠合性能間之關係。

【關鍵字】單一影像多層分析技術（SIMPA）、解體材、粒片板、內聚強度、內部膠合面積、接觸角

I. INTRODUCTION

Wood-based resources have regarded as one of the eco-materials since the end of twenty century (Kutsca, 1999). The development and utilization of various wood-based boards become an important issue due to the quantity become insufficient. To correspond with the ideals of environmental conscious materials (Kuwahara, 1994) and cascade utilization of wood-based resources (Akiyama, 1998), the utilizations of recycled demolition wood-based panels (RDWP) to composite products (such as particleboard, fiberboard and oriented strand board etc) are became one of the tendencies at forest products industry (Suzuki, 1993). The reconstitution process disperses natural defects of the wood, resulting in more consistent and uniform mechanical and physical properties compared to those of solid sawn lumber. Composite products constitute a more efficient utilization of fiber resources. However, the wettability of RDWP surface was worse than wood. The particleboard with RDWP should be to evaluate its bond quality. Ultimately the aim should be to improve (or maintain) mass-particleboard performance.

The objective of this study was to establish if the bonded areas obtained from the internal bond tests, in conjunction with an image processing analysis and a contact angle measurement, could be used to determine the particleboards of structural mechanics (internal bond strength). This involves the resin distribution and particle resin coverage differences arising from changes in internal structures such as: types or compositions of particles. The experimental RDWP particles for this study were from three types of commercial boards. The particleboard specimens were mixed with planer shaving-particles of China fir and RDWP particles. The mixture proportion changed in every 25% from 0% to 75% based on the whole weight of the board. Handmade laboratory scale particleboards with various mixture proportions of RDWP were manufactured. After IB tests, the fracture portions were examined using the single image multi-processing analysis (SIMPA) techniques to evaluate the bond quality using internal bonded areas, an image-processing parameter. Furthermore, the board surfaces of China fir wood and various boards were measured individually using contact angle meter. The contact angle obtained was to evaluate the influence of the mixture proportions or the types of composed particles on internal bond (IB) strength for RDWP particleboards.

Previous work (Lin *et al.*, 2001) using fade effective image processing analysis (FEIPA) technique established a relationship between the internal bonded areas of the fracture portion and IB strength for particleboards with various particle sizes or densities. The internal bonded areas in particleboard combined with observations of fractured portions could provide an experimental data for evaluating the internal bond state of particleboards. The main difference between FEIPA and SIMPA techniques was determined using the image processing with the paint over command in Picture Publisher software (Micrografx (R) Inc., Version LE-J). The FEIPA techniques use a fade effective minus mode to evaluate the void areas and the bonded areas on the fractured side (portion) of the board. The SIMPA techniques use the fade effective minus mode and fade effective plus mode to evaluate the difference of internal bonded areas between RDWP and China fir particle areas (as a nominal wood particles).

II. MATERIALS AND METHODS

(I) *Preparation and manufacture of particleboard specimens*

This study concentrated on handmade laboratory scale particleboard manufactured with the mixture proportion of China fir (*Cunninghamia lanceolata* (Lamb.) Hook. var. lanceolata) particles and various commercial boards as particles of the recycled demolition wood-based panels (RDWP). These particles were used planer-shaving particles. The experimental RDWPs included 914 × 1829 × 3 mm of polyvinyl chloride single-overlaid plywood (PVCOP), 1219 × 2438 × 12 mm of structural plywood with single spread of melamine resin coatings (MSP) and 914 × 1829 × 9 mm of plywood with urea formaldehyde resin adhesive (UFP). The China fir particles and those boards used were from the Dantani Corporation, a particleboard plant in Japan. After three types of RDWPs processed with shaving planer, these particles were sifted through 4 screen fractions, On 8, 8 to 12, 12 to 24, and through 24 mesh. The length and the width of the particles screened for each particle size were measured with a caliper. The particle size became larger with the decrease in the mesh number. The size (standard deviation) of the length and the width for On 8 mesh of the particles was 19.32 (7.94) and 4.32 (2.16) mm, followed 13.66 (5.75) and 2.01 (0.50) of the 8 to 12 mesh particles, 7.03 (2.99) and 1.10 (0.33) of the 12 to 24 mesh and 3.53 (1.47) and 0.66 (0.19) of through 24 mesh.

The mixture proportions of China fir/RDWP used were 100/0, 75/25, 50/50 and 25/75. The average moisture content (MC) of the particles before spraying adhesive was from 4.3 to 6.1%. Single layer particleboards were manufactured at a nominal board density of 0.7 g/cm^3 in the laboratory. These board types were manufactured with a phenol-formaldehyde resin (Oshika Shinko CO., LTD. in Japan, PB-1310) of 8% content. Wood particles of a constant weight were sprayed with 48.5% resin solids in a transparent vinyl bag and stirred by hand (under the bottom of the bag). Particle mat formations were hand-formed, 36.5 cm in length and 25.5 cm in width, in a rectangle frame. Handmade particleboards were manufactured with pressure of 30 kgf/cm^2 at 180 OC for 12 min with the distance bars at 20 mm (board thickness). Three replicates were manufactured for each particleboard according to the mixture proportions used. The specimens were cut into 50 mm squares and then conditioned to equilibrium at 20 OC and 65% relative humidity (RH) for at least 4 weeks until the average MC of the particleboard specimens was about 8%.

(II) *Experimental methods*

a. Tensile tests perpendicular to the particleboard plane

The mixed ratio for two types of epoxy resin and polyamide-curing agents (Nagase Chiba Corp. Stand Araldite) was 1 to 1, and then used to bond the particleboard specimen to steel loading blocks. The IB strength was determined by examining the thickness direction of the specimen. A tensile force was run through a 500 kgf load cell at a loading speed of 2 mm/min (JIS A 5908 - 2000) using an INSTRON type strength test machine (Toyo Baldwin CO., LTD. Tensilon STM-F-1000).

b. Image processing analysis

An example of the single image multi-processing analysis (SIMPA) techniques to analyze internal bonded areas from the fractured portion of particleboard with the particles mixture proportion of China fir / PVCOP (75/25) for the first step is shown in Fig. 1 and second step is shown in Fig. 2. After the IB tests, the specimen separating onto the two steel loading blocks was arranged with a ruler and then a photo was taken using a digital camera (Sony DSC-P1 Japan, 3 million pixels) with 2 lighting unit lamp (Nikon Japan, PL3 500W each). Each photograph (image) was transmitted into computer and saved as a file. The image file was opened using Picture Publisher software (Micrografx (R) INC., Version LE-J). The clear-cut feature command from the mask mode tool selection was used to take a unit set and the diminution-image area. The diminution-image area was as a total area (X portion), including the void and substance areas (Y portion). The substance area, including the mixture proportion of China fir/RDWP particles, was obtained using the fade effective minus mode. Both portions, using FEIPA technique based on the diminution and substance-image areas, were analyzed. The method of FEIPA technique was described in a previous study (Lin *et al.*, 2001). To analyze the internal bond-image

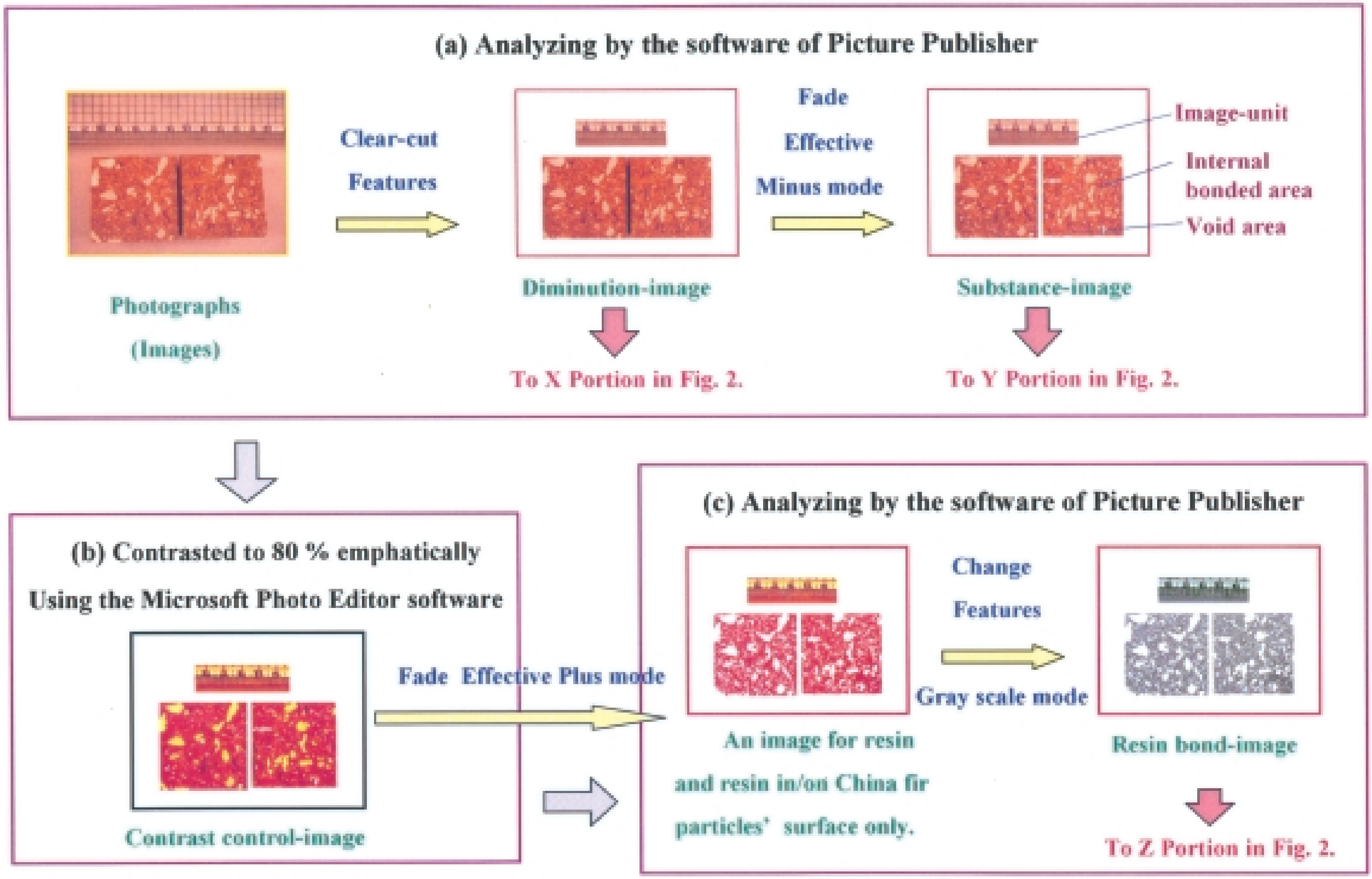

Fig. 1. First step of the single image multi-processing analysis techniques.

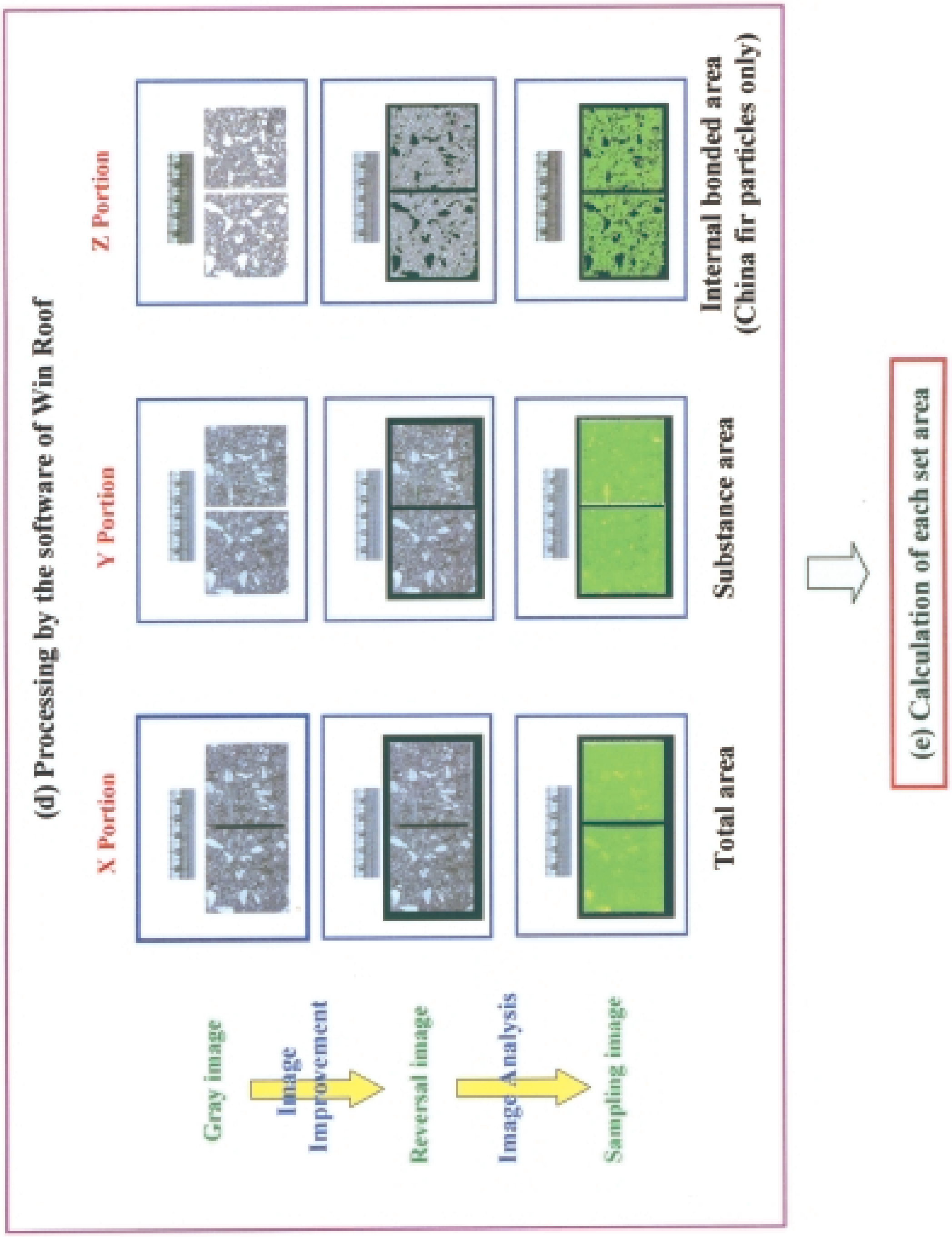

Fig. 2. Second step of the single image multi-processing analysis techniques.

for China fir (Z portion), the substance-image was contrasted to 80% using the image effective command from the Microsoft Photo Editor software. The fade effective plus mode with clear-cut features using the smart mask mode tool selection was used to obtain an image of the internal bonded area, including the resin and resin in/on China fir particles' surfaces. In other words, using the fade effective plus mode the resin and resin in/on RDWP particles' surfaces were taken out. After that, this resin bond-image feature was changed using the gray scale mode. The gray-image was prepared in the second step.

Three portions (X, Y and Z) with their unit image, obtained from the first step, were analyzed using Win Roof software (Mitani Corporation, Version 3.03), shown in Fig 2. This method was described in a previous work (Lin *et al.* 2001). The total area calculated with the substance area (Y portion) and obtained the void area (X portion minus Y portion, X-Y). The RDWP bonded areas were obtained from X portion minus the void area minus Z portion (X-(X-Y)-Z). In other words, the substance area minus China fir bonded area (Y portion minus Z portion, Y-Z) was equal to the RDWP bonded area. After these sampling images were taken, each area with its standard scale set was obtained automatically using the measurement areas calculation program. The correlation among each bonded areas for particleboards with various mixture proportions was examined using Duncan's multiple range tests (5% level).

c. Measurement of contact angle

The 50-mm square specimens were cut and then prepare to evaluate contact angle. Using contact angle meter (Face contact angle meter CA-D, Kyowa meter FACE science CO. LTD), the contact angle for each board surfaces of China fir and various boards according to this study used was measured respectively. Using droplet-measuring method, the surface is brought into contact with a liquid (water) by mechanical means. With micro-head scale division of 20; the resulting droplet is about 1.5 mm in length. Adjust the rotary cross ring to 45°, Contact the peak of the contact between the left droplet tube and the surface with a straight line. Take twice the angle on the extension as a contact angle. Six replicates on each specimen surface were measured.

III. RESULTS AND DISCUSSION

(I) Mixture proportion of various RDWP particles effect on IB strength and internal bonded areas

To examine the influence of mixture proportion of various RDWP particles on IB strength and internal bonded areas, handmade boards with a constant board density (0.7 g/cm^3) and resin content (8%) using different mixture proportion were manufactured. The weight proportion of each RDWP particles to the total weight was changed in each 25% from 0% to 75%.

The relationship between different types of RDWP particles produced by each mixture proportion with the IB strength is shown in Fig. 3. By mixing less RDWP particles, IB strength was increased for each type of particleboard. The board with less RDWP particles at constant resin content had more amount of the adhesive in a unit surface area (Akiyama, 1998). IB strength increased because the adhesion between particles was strengthened (Suchsland, 1989). It was thought that IB strength decreased because the bonded quality decreased with increasing RDWP mixture proportion for each type of RDWP.

The influence of mixture proportion on internal bonded areas of China fir and RDWP for

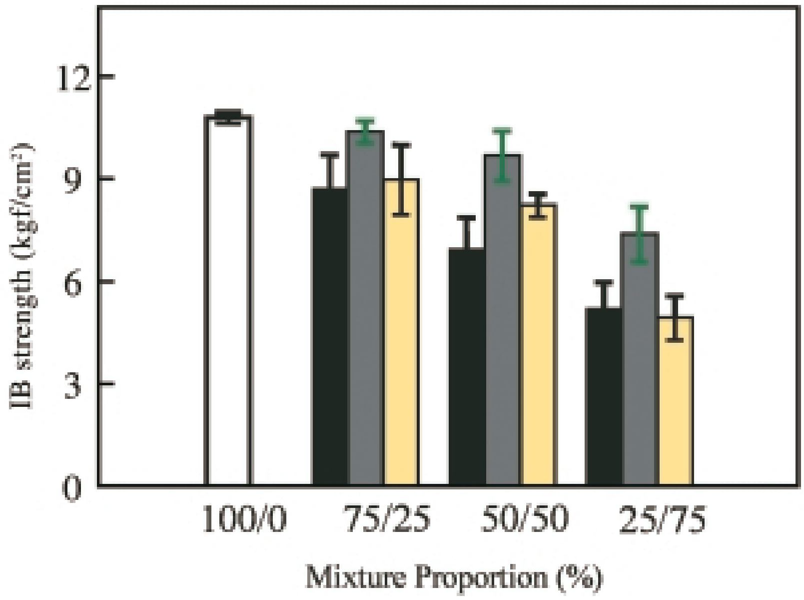

Fig. 3. Effect of mixture proportion on IB strength for various remade particleboard specimens.
Legend Type of partucles- ☐ China fir, ■:PVCOP, ■:MSP, ■:UFP.
Note Abbreviations are the same as Table 1.

each particleboard is shown in Table 1. After analyzing by Duncan' s multiple range tests, results show that the mixture proportions of particles significantly affected the internal bonded areas (bonded area of particles for China fir or RDWP). The significant difference was found among control and various RDWP particleboards. Moreover, the RDWP mixture proportion of particles increased with either decreasing bonded area of China fir or increasing boned area of RDWP in accordance with each type of RDWP. The image analysis of the internal bonded areas suggested that using SIMPA techniques to analyze the bonded areas for the type of RDWP particles or the mixture proportion of RDWP from the particleboard could be useful in evaluate the distribution of particle types.

A theoretical value for the IB strength was calculated using maximum value at failure (kgf) for the specimen area (cm^2). However, the IB strength provides direct information on the adhesion of the particles (Nishimura, 1997). It is indicated that the internal bonded areas on the fracture portion are the actual tested areas. The data analysis therefore compared the IB strength obtained from the tested specimens (Fig. 3) and the IB strength evaluated from the bonded areas (Table 1). It was indicated that particleboards manufactured with various types of RDWPs or RDWP mixture proportions under the same resin content consisted of areas with the difference of bonded quality. Younquist *et al.* (1987) observed

Table 1. Effect of mixture proportion on bonded areas of China fir and RDWP.

Mixture proportion (%)		Board density (g/cm³)	Moisture content (%)	Bonded area of China fir (cm²) (1)	Bonded area of RDWP (2) (cm²)
Type	China fir/RDL			Z portion	Y-Z Portion
Control	100/0	0.65 (0.02) a	8.00 (0.13) a	42.15 (0.93) a (3)	0.00 (0.00) a
PVCOP (2)	75/25	0.68 (0.01) a	8.63 (0.17) a	38.14 (0.65) b	8.22 (0.25) b
	50/50	0.66 (0.02) a	8.13 (0.14) a	30.12 (0.73) bc	12.14 (0.15) c
	25/75	0.67 (0.01) a	9.00 (0.17) a	28.02 (0.63) c	14.02 (0.69) cd
MSP (2)	75/25	0.68 (0.02) a	8.58 (0.16) a	36.13 (0.15) b	7.45 (0.15) b
	50/50	0.67 (0.01) a	7.75 (0.10) a	34.12 (0.73) b	10.15 (0.26) c
	25/75	0.68 (0.01) a	8.84 (0.01) a	25.11 (0.90) c	13.02 (0.25) cd
UFP (2)	75/25	0.68 (0.01) a	8.36 (0.11) a	40.53 (0.85) ab	4.41 (0.25) b
	50/50	0.66 (0.01) a	9.22 (0.12) a	34.99 (0.62) c	8.14 (0.29) bc
	25/75	0.68 (0.02) a	8.95 (0.13) a	29.66 (0.56) c	10.24 (0.63) c

(1) Bonded areas presents 2 fracture portions by image processing analysis after the IB (internal bond) tests.

(2) Recycled demolition wood-based panels (RDWP), Polyvinyl chloride single-overlaid plywood (PVCOP),Structural plywood with single spread of melamine resin coatings (MSP),Plywood with urea formaldehyde resin adhesive (UFP).

(3) Mean (standard error) separation within columns by Duncan's multiple range tests at 5% significant level.Same alphabet is defined as insignificant difference between two variable factors.On the contrary, significant difference is expressed by different alphabet.

that altering resin application methods caused changes in the bonded quality of resin distribution or particle coverage differences. Uniform resin distribution throughout a panel produced boards with the highest IB strength. It was therefore suggested that the IB strength was closely related to the internal bonded areas, that is, the different type of the particles influenced the IB strength because of the difference of bonded quality.

(II) Effect of Contact angle on IB strength and Internal bonded area

To examine the influence of the bonded quality on the IB strength, the contact angle on the surface of each commercial board and China fir was tested using contact angle meter. The results are shown in Table 2. As expected, the contact angle changed on each type of specimen. Contact angle 31.8° for China fir was smaller than the other commercial boards, followed 40.7° of PVCOP, 41.1° of UFP and the largest one, 52.1° for MSP. The contact angle is an important parameter in interface science; it is common measure of wettability (hydrophobic/ hydrophilic property) of a solid surface. This is because the contact angle measurements can be used in the evaluation of wettability and adhesion (Lam, 2002). In general, the greater the contact angle, the less the internal bond strength obtained. It is said that IB strength becomes greater when the contact angle is smaller. Therefore, the type of RDWP as the particles or the mixture proportion of RDWP for manufacturing particleboard had a close relationship with the IB strength. Such data suggests that the initial number of bonds (assumed to be proportional to the RDWP and China fir particles) is related to the number of failing bonds (proportional to both bonded areas). In these boards, the resin content, density and manufacturing conditions were uniform. Assuming that the mat lay-up process was identical, only the type of RDWP as the particles or the mixture proportion of RDWP could vary the bond strength. It is suggested that using contact-angle meter to analyze the contact angle from each RDWP surface could be useful to evaluate whether or not the bonded quality in the internal portions of the board indirectly and allow evaluation of the internal bond state of the particleboard.

IV. CONCLUSIONS

Particleboard specimens were manufactured with various types of particles for RDWPs or the mixture proportions of particles from China fir/RDWP. The bonded quality of particleboard for IB strength tested by IB tests and China fir and RDWP bonded areas evaluated by SIMPA techniques were changed as a result of the mixture proportion effect. Results showed that the type of RDWP and the RDWP mixture proportions determined IB strength of board. This indicates that either bonded area is also related to the bonded quality. The contact angle for the board surface of China fir and three types of commercial boards are indirectly enabled to evaluate IB strength, even if the types of particles were changed as a result of the mixture proportion effect. These results suggest that using image processing analysis to measure both China fir and RDWP particle bonded areas in the board

Table 2. Contact angle for various board surface of each specimens.

Type of specimen		Contact angle (°)
China fir		31.8 (0.22) [5]
RDWP (1)	PVCOP [2]	40.7 (0.11)
	MSP [3]	52.1 (0.25)
	UFP [4]	41.1 (0.11)

[(1), (2), (3) and (4)] Abbreviations are the same as Table 1.

[5] Mean (standard deviations) separation within columns.

combined with contact angle examination may provide an experimental method for understanding the IB state of particleboards.

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