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Apply Fade Effective Image Processing Analysis Technique to Evaluate Internal Bond Strength of Particleboard

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【Abstract】Commercial wood particles, screened at 4 particle sizes, were prepared for producing particleboard specimens made of each particle size with a constant density and board manufactured at 3 different densities from the same particle size. After the internal bond strengths were tested, the designed method of the fade effective image processing analysis (FEIPA) was used for measuring the internal bonded areas in particleboard specimens. The micrograph viewpoint on the fracture appearances was observed using a stereoscopic microscopic examination to determine fracture conditions for evaluating the influence of internal structural factors on the internal bond strength of particleboard. Results indicated that for greater the internal bond strength at the same amount of resin content, larger particle sizes with smaller bonded areas or greater density with smaller voids and a fewer number of discontinuities are required. Moreover, a particleboard specimen manufactured with a higher density formed a higher panel densification during the hot pressing. This was resulted in a greater number of bonded areas among the particles, as well as the increased in the internal bond strength relatively. Using the FEIPA to measure the internal bonded areas in particleboard combined with fracture portions observations could provide an experimental data for referencing the internal bond state of particleboards.

【Key words】Fade effective image processing analysis, Particleboard, Internal bond strength, Internal bonded areas.

應用消色影像分析技術評估粒片板之內聚強度

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【摘要】商用木質粒片，經 4 種不同網目之篩網篩分後使用之，抄製成相同密度之粒片板。並再以相同粒片尺寸及不同密度等組合製成試驗用粒片板。切製成 5 × 5 cm 試片，經由測定內聚強度後，使用所設計之消色影像分析（fade effective image processing analysis, FEIPA）技術評估其破壞面之內部膠合面積（internal bonded areas）。再以立體顯微鏡觀察破壞面之顯微外觀作對照。藉以分析粒片板組成因子對內聚強度之影響。試驗結果顯示，所製成之粒片板中具較大粒片者，因其膠合面積較小，於相同用膠量下，相對之布膠量較高，則得較高之內聚強度，而較小粒片者，則

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得到相反結果。又知，較高密度之粒片板，熱壓過程使粒片板產生較高之緻密化，導致膠合面積增多，相對提高粒片板之內聚強度。因此應用 FEIPA 技術能有效分析粒片板破壞面之膠合面積大小與內聚力兩者間之關係。

【關鍵詞】消色影像分析技術，粒片板，內聚力，內部膠合面積

Ⅰ. INTRODUCTION

Wood-based composite products are engineered material. Their performance is governed by the properties of the wood species, adhesive, manufacturing strategy, and production process. Composite products are formed by arranging particles (chips), flakes, strands, fibers or sheets of veneer etc., bonded together with adhesive under heat and pressure to manufacture panels or dimensional lumber-like products. In general, the reconstitution process disperses natural defects in 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.

Particleboard, one of the wood-based materials, has been widely utilized in many industrial and domestic applications, such as the structural members in furniture or architecture. It can be manufactured to different specifications or qualities for various applications. Particleboard testing during manufacturing and prior to use is an area of special importance. In this field, one such design involving the fastening of particleboard internal structures has been determined using the tensile strength perpendicular to the plane (internal bond strength), which plays an important role in the detailed analysis and provides direct information on the adhesion of wood particles.

The bonded area in panel products is believed to have a significant impact on panel properties. Development of a method to quantify bonding areas should provide opportunities to improve particleboard performance by achieving optimized panel properties using basic knowledge of particleboards made from particles of various sizes and board density and determining the internal bond (IB) strength during tensile tests perpendicular to the particleboard plane. Development of a method to measure particle bonded areas within particleboard panels will help towards a better understanding of the factors involved in particle bond development and panel properties. Ultimately the aim should be to improve (or maintain) product performance in mass-particleboard.

Determination of bonded areas in wood panel is difficult due to the opaque nature of the resin and the uneven resin distribution when the panels are cured. Some research has attempted to visualize bonded areas directly using light microscopy techniques (Donaldson and Lomax, 1989). Observations of the resin distribution have been attempted using SEM (Butterfield *et al.*, 1992). The results were not overly successful. Ellis *et al* investigated the measurement of macro-void areas using two imaging systems: a video camera and a line scan camera. Such methods are useful, but they are time-consuming. Another approach is to use X-ray computer tomography (CT) techniques. The requirements are too expensive for general use even though a database from a series of cross sectional density distributions in strand-based wood composites has been established (Masatoshi Sugimori *et al.*, 1999).

The objective of this study was to establish if the bonded areas obtained from the IB tests, in conjunction with an image processing analysis and a stereoscopic microscopic observation, could be used to determine the structural mechanics of particleboards (IB strength). This involves the resin distribution and particle resin coverage differences arising from changes in internal structures such as: particle size and panel density. The bonded areas were examined in handmade laboratory scale particleboards after the IB tested and the fracture portions in the bonded areas were observed.

Ⅱ. MATERIALS AND METHODS

(Ⅰ) *Preparation and manufacture of particleboard specimens*

This study concentrated on handmade laboratory scale particleboard manufactured with general-purpose commercial particles. The particles used were shaving-type wood particles from a particleboard plant in Japan, the Dantani Corporation. Single layer particleboards were manufactured at a density of 0.7 g/cm^3 in the laboratory after the particles were subdivided into 4 screen fractions, On 8, 8 to 12, 12 to 24, and through 24 mesh, respectively. A nominal board density of 0.5, 0.6, and 0.7 g/cm^3 using particles from 8 to 12 mesh was also projected as the manufacturing condition for the experimental particleboards. Both board types were manufactured with a phenol-formaldehyde resin (Oshika Shinko CO., LTD. PB-1310) of 8 % content. The average moisture content (MC) of the particles before spraying adhesive was 6.1 %.

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. Boards were manufactured with 30 kgf/cm^2 hot pressing at 180℃ for 12 min with the distance bars at 20mm (board thickness). A commercial three-layer particleboard, made with urea-melamine formaldehyde (UMF type) adhesive, was also used as one of the specimens in this experiment. The basic properties of this particleboard are shown in Table 1 For all handmade and commercial boards, the specimens were cut into 50mm squares and then conditioned to equilibrium at 20℃ and 65% relative humidity (RH) for at least 4 weeks until the average MC of the particleboard specimens was about 8%.

(Ⅱ) *Experimental method*

a.Tensile tests perpendicular to the particleboard plane

Two types of epoxy resin and polyamide curing agents (NAGASE CHIBA Corp. Stand Araldite) were mixed and used to bond the specimen to steel loading blocks. The IB strength was determined by examining the thickness of the particleboard specimen. A tensile force was run through a 500 kgf load cell at a loading speed of 2 mm/min (JIS A 5908-1998) using an INSTRON type strength test machine (TOYO BALDWIN CO., LTD. TENSILON STM-F-1000).

b. Image processing analysis

Because the fracture side consideration included the bonded and void areas after the *IB* tests, the bonded areas were imaged based on two conditions as follows:

(a) Fracture portions:

(aa) Particle-self fracture,

(ab) Bonded layer fracture (adhesive layer

Table 1. The physical and mechanical properties of the commerical particleboard used in this experiment.

Properties	Commerical particleboard
Thickness (mm)	20.30 (0.12)
Moisture content (%)	8.1 (0.20)
Density (g/cm^3)	0.74 (0.03)
Internal bond strength (kgf/cm^2)	7.16 (0.65)
Modulus of rupture (kgf/cm^2)	173.6 (6.60)
Modulus of elasticity (×10^3 kgf/cm^2)	27.21 (0.97)
Remarks	3 layers UMF

UMF:Urea-melamine formaldehyde resin adhesive
Values in parentheses are the standard deviations

fracture).

(ac)Surface fracture between particles and bonded layer.

(ad)Interweaved particle fracture before IB tests.

(ae)Mixed fracture, including (1), (2), (3) and (4).

(b) No fracture portions:

(ba) An insufficient adhesive area.

(bb) No adhesive on particles.

The bonded areas considered in this study, expressed by the total areas including (a) and (b) conditions were examined using image processing analysis. An illustration of the photo-image processing analysis is shown in Fig. 1 After the IB tests, the specimen boned 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). The photo-image was transmitted into computer and saved as a file. The photo-image file was opened using Picture Publisher software (MICROGRAFX (R) INC., Version LE-J). The clear-cut features command from the mask mode tool selection was used to take a unit set and bonding area photo image. A diminution-image was obtained using the paint over command. This image produced a contrast shape from the image effective command. The fade effective (gradation affect) command with clear-cut features using the smart mask mode tool was used to obtain the bonding area images, which were saved into another file.

The bonded area and a unit image files were recalled using Win Roof software (MITANI Corporation, Version 3.03). The bonded area calculations on the fracture side were obtained as follows. First, a datum line for the length was set using a measuring environmental command. This length was then calibrated as a standard scale from the unit-image. The length was set at 10 mm as a standard unit for each specimen in this study. Measurement area selection was carried out using a ribbon set command. The gray image for the bonded areas was obtained using the gray

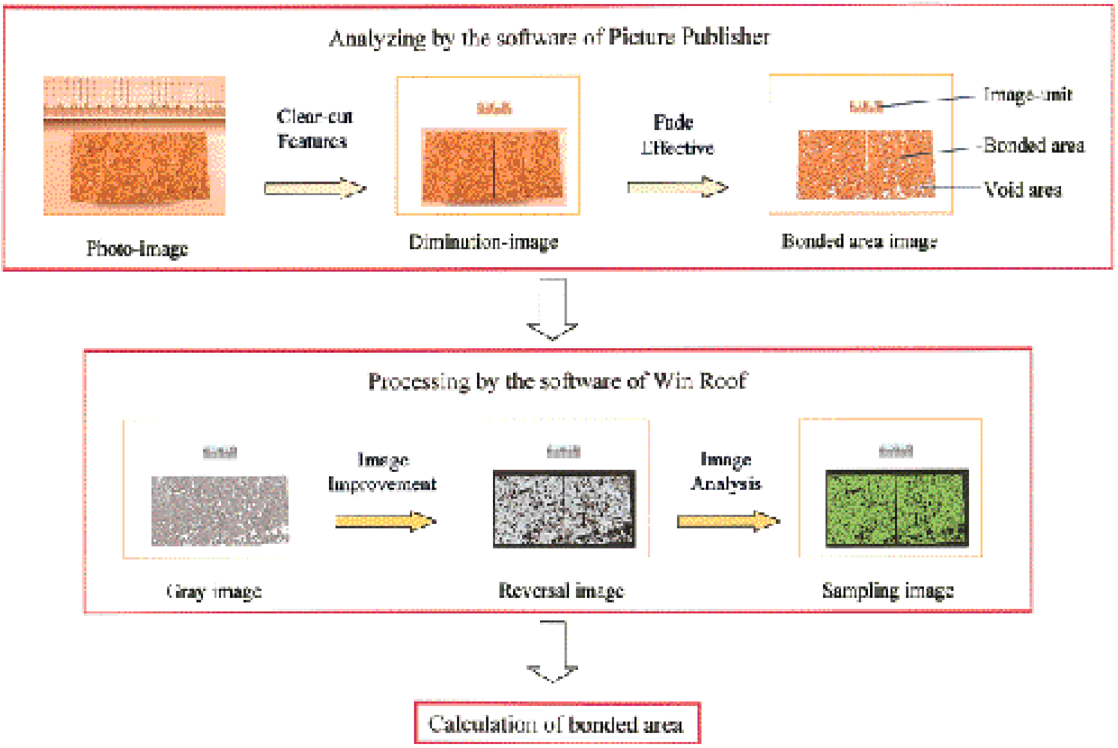


Fig. 1. An illustration of the photo-image processing analysis.

image processing command. From the image improvement (conventional image-process), these images were converted into reversed black and gray images. The dark areas corresponded to the void areas and the gray (light) areas to the bonded areas. After these image-taken, the measuring areas sampling command from the image analysis was used to obtain a sampling image, and designated a rather high density of image color (green) on the bonded areas (gray areas). Finally, the bonded areas in accordance with a standard scale set before were obtained under the measuring areas calculation program automatically from the sampling image taken.

c. Stereoscopic microscopic examination

The fracture appearances were observed after obtaining the bonded area images using a stereoscopic microscope (NIKON Japan, Leica Mz12). A digital camera (FUJI Japan, HC 3001, 3 million pixels) was connected and used to take photo observations. The photo-images were shown directly on the monitor using Adobe Photoshop software (PANTONE INC., Version 5.01). The boned areas, particle-self, bonded layer, surface and interweaved particle fractures were observed.

Ⅲ. RESULTS AND DISCUSSION

(Ⅰ) *Particle size effect on bonded areas and* IB *strength*

To examine the influence of particle size on the bonded areas, handmade boards with a constant board density and resin content made using different particle sizes were manufactured. The relationships between the length and width of the particles, board density, moisture content and the bonded areas of each particleboard are shown in Table 2. Results show that the particle size, even of equal densities, significantly affected the bonded areas. The most significant difference was found between the largest and the smallest particles. In general, the total particle surface areas increased when the particle size became smaller. It was suggested that this increase in surface area was related to the length and width of the particles.

The relationship between different amounts of bonded area produced by each particle size with the IB strength is shown in Fig. 2 It was indicated that particleboard manufactured with smaller particles under the same resin content consisted of areas with insufficient or/and no resin (Fujimoto Y. *et al.*, 1997). Younquist and Murmanis (1987) observed that altering resin application methods (solids content, application rate and amount of blending) caused changes in the resin distribution and 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 bonded areas, that is, the length and/or width of the particles influenced the IB strength because the particles were flattened in the horizontal direction during the manufacturing process.

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 wood particles. It is indicated that the bonded areas are the actual tested areas. The data analysis therefore compared the IB strength obtained from the tested specimens and the IB strength evaluated from the bonded areas. Results are shown in Fig. 3 The IB strength decreased when the particle size became smaller by degrees at equal board density, 0.7 g/cm^3. It is suggested that the bonded areas and voids are involved in the IB strength. The voids and/or discontinuities on the fracture side were negatively related to the bonded areas. The IB strength increased with a corresponding increase in voids or discontinuities. This indicated that the larger the particles in a board at hot pressing, the less the particle

Table 2. Effect particle size on the bonding area, and the length and width of particles for each fraction.

Fraction (mesh)	Length (mm)	Width (mm)	Board density (g/cm^3)	Moisture content (%)	Bonding area (cm^2)
On 8	19.32(1.45)a	4.32(0.39)a	0.65(0.02)a	8.00(0.13)a	40.72(0.65)a
8 to 12	13.66(1.05)b	2.01(0.09)b	0.68(0.01)a	8.13(0.14)a	42.01(0.55)ab
12 to 24	7.03(0.55)c	1.10(0.06)c	0.66(0.03)a	7.95(0.30)a	42.15(0.93)ab
Through 24	3.53(0.27)d	0.66(0.03)c	0.67(0.01)a	7.79(0.11)a	44.58(1.16)b

Value in parenthesis represents standard error.
Mean(standard error) seperation within columns by Duncan's multiple range test, 5%.
Bonding area presents 2 fracture sides by image processing analysis after IB(internal bond)tests.

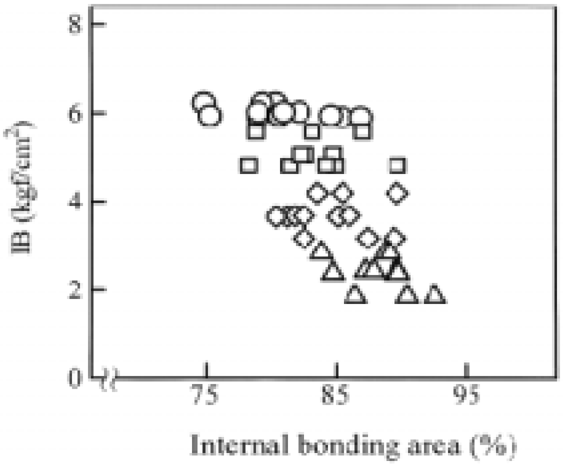


Fig. 2. Relationship between IB strength and internal bonding area for various particle sizes in particleboard specimens.

(Legend Particle size(mesh) ○: On 8 □: 8 to12 ◇: 12to 24 △ : Through 24)

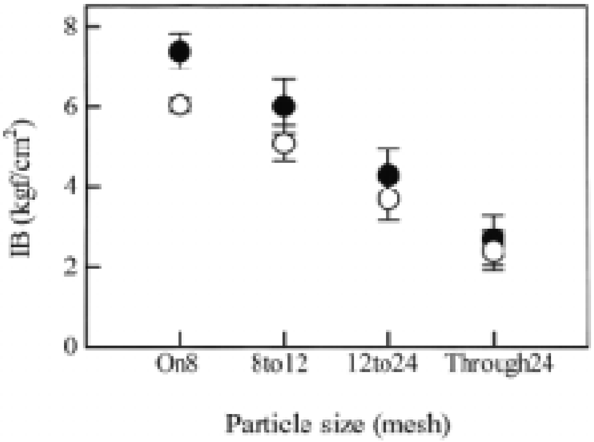


Fig. 3. Effect of particle size on IB for particleboard specimens in varying particle sizes.

(Legend ● : IB strength evaluated image processing analysis ○ : IB strength in IB tests)

deformation because of particle rigidity. Results also indicated that the larger the particles, the larger the difference between the theoretical IB strength and the actual IB strength. It might be indicated that this difference indicates a larger number of voids or a greater number of discontinuities on the fracture side.

(II) *Board density effect on bonded areas and IB strength*

In order to examine the influence of the bonded areas on the IB strength for particleboards with different density, single layer particleboards were manufactured with 8 to 12 mesh particles under 3 levels of board densities, 0.5, 0.6, and 0.7

g/cm^3. The relationship between the IB strength and void area (%) for various densities are shown in Fig. 4 IB strength became larger with smaller void areas because of panel densification. IB strength for 0.7 g/cm^3 board density had the highest value, followed by 0.6, 0.5 g/cm^3 in that order. The void areas had the highest value at 0.5 g/cm^3 followed by 0.6, 0.7 g/cm^3. This suggested that the IB strength was negatively related to the void areas at the same level of density.

Moreover, various board densities involved voids. The solid board volume included particles and adhesive. The voids among the particles and adhesive for the specimens manufactured with higher board density were less than that for boards with lower board density. The bonded areas were obviously larger because the number of particles and amount of adhesive were greater. The bonded areas were more expansive than those in a less dense board. It was confirmed that the IB strength increased and the void areas were smaller in a higher density boards.

(Ⅲ) *Observation of the fracture appearance*

The above-mentioned bonded areas were observed under stereoscopic microscopic examination. The main purpose of this observation was to determine the fractured portions after IB tests because the IB strength obtained direct information from the adhesion of the wood particles. For portions with no fractures in this examination, the resin distribution could not be distinguished from the surface particles using color or quantity under stereoscopic microscopic observation because of the insufficient adhesive and/or no adhesive on the particles.

One of the observed bonded areas in the commercial particleboard in this study is shown in Fig. 5 This observation determined particle fracture that was enlarged 10, 20 and 63 times. A particle fracture at 63 times magnification was observed after the IB tests. It was considered that the adhesive was stronger than the stress level of the particle after the IB tests. In other words, the quantity of adhesive used was a suitable inner layer for manufactured board under heat and

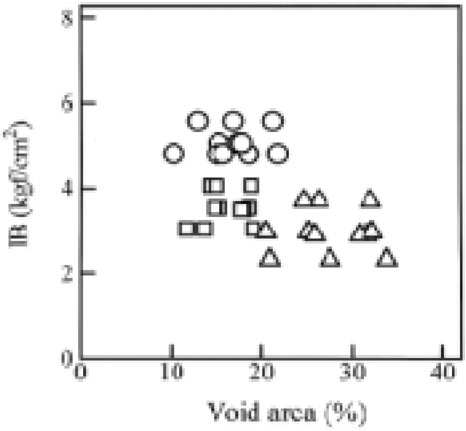


Fig. 4. Relationship between IB strength and void area for various densities in particleboard specimens. (Legend Board density(g/cm^3) ○: 0.7 □: 0.6 △: 0.5)

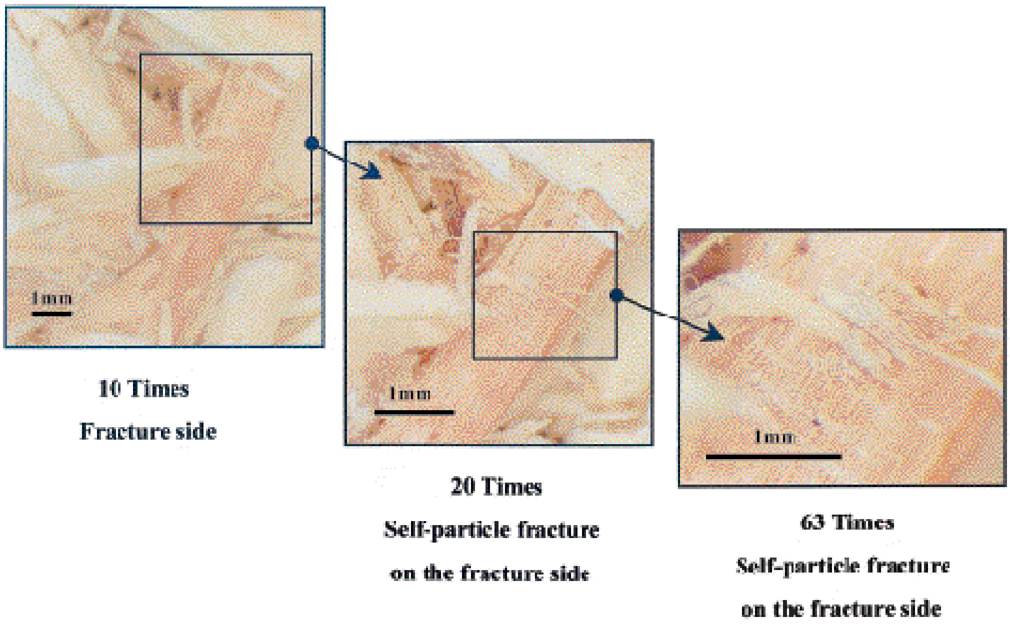


Fig. 5. A microscopic photograph of the fracture side for the commercial particleboard.

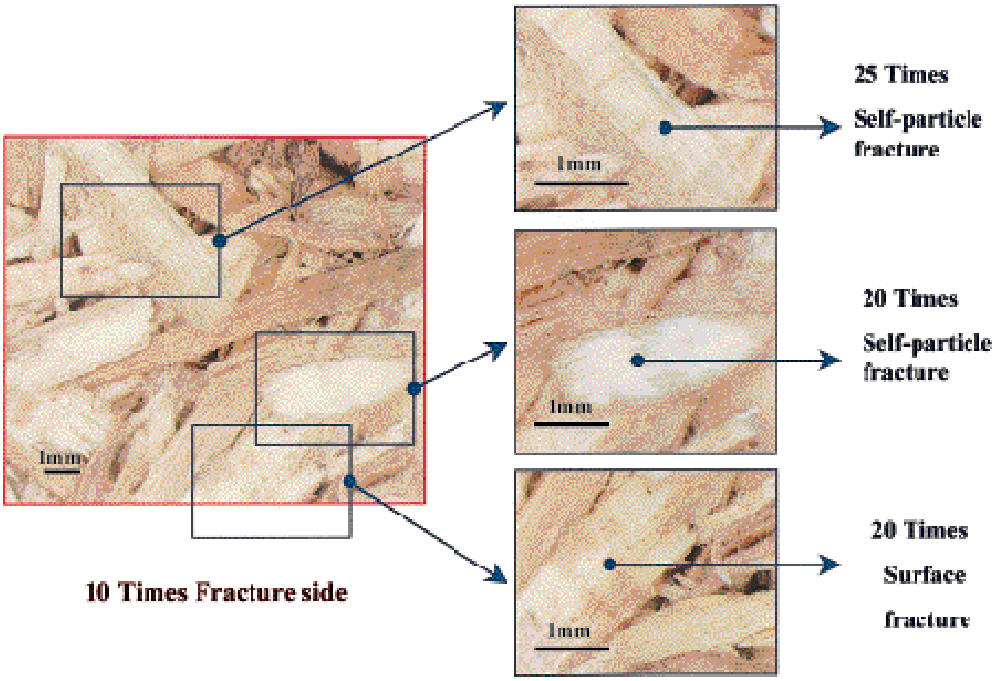


Fig. 6. A microscopic photograph of the fracture side for the particleboard manufactured with resin content of 8% at density of 0.7 g/cm^3 using the particles of 8 to 12 mesh.

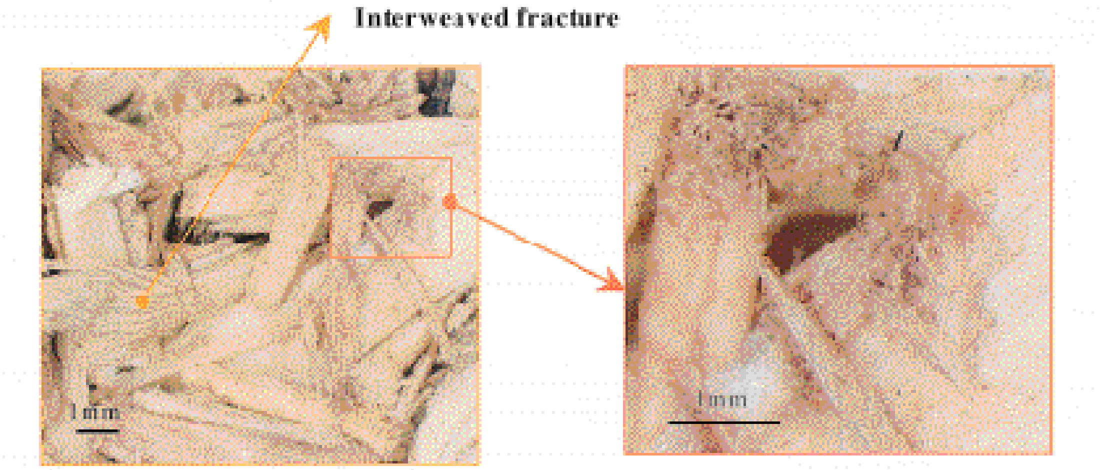
pressure conditions, which produced a perfect adhesive hardening.

An example of a stereoscopic microscopic photograph of the handmade particleboard, manufactured with 8 % resin content at a density of 0.7 g/cm^3 using 8 to 12 mesh particles is shown in Fig. 6 Particle and surface fractures were found in the bonded areas. A surface fracture at 20 times magnification at the lower right in Fig. 6 between the particles and bonded layer was found. This was concerned with two considerations as follow: The particles in this specimen had an effective surface area and therefore areas with sufficient resin. The resin distribution in this specimen was irregularly and/or unevenly sprayed during the hand forming process.

To observe the fracture portions of specimens at varying densities, panel densification was considered. As the density increased during hot pressing, heat from the steel platen was effectively transmitted to the center layer of the mat. Substantial voids between the particles decreased and the interfaces between the particles were closed. All of these factors improved the IB quality through an increase in bonded points. However, the particles at the high-density level were interweaved because the particle rigidity was lost. As expected, an interweaved fracture was observed at higher board density (see Fig. 7). In other words, the resin interweaved between the particles in the bonded area was one of the factors improved the IB quality. Thus, with increased density, substantial bonded points increased and the void areas decreased among the particles.

Ⅳ. CONCLUSIONS

The interrelation among particle size, density, IB state and the bonded areas were investigated on laboratory scale particleboards. Results indicated that particle size and density



10 Times : Fracture side

25 Times : Interweaved fracture

Fig. 7. A microscopic of the fracture side for the particleboard at density of 0.7 g/cm^3 manufactured with 8% content using particles size of 8 to 12 mesh.

determined IB strength. From the bonded area examinations and fracture appearance observations, the distribution of the particles and resin were significant factors that influenced IB strength. These results suggest that using image processing analysis to measure the internal bonded areas in particleboard combined with fracture portions observations may provide an experimental method for understanding the IB state of particleboards.

Ⅴ. ACKNOWLEDGEMENTS

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