목재공학 24(2) : 61~70
Mokchae Konghak 24(2) : 61~70, 1996

Micromorphological Features of MDF Fiber Surface and Adhesives Distribution in MDF[*1]

Jae-Woo Kim · Sang-Jin Park[*2]

MDF 纖維의 表面 形態와 接着劑의 分布 觀察[*1]

金 載 祐 · 朴 相 珍[*2]

요 약

針葉樹材(Radiata pine, *Pinus radiata*)MDF와 闊葉樹材(Rubber wood, *Hevea brasiliensis*)MDF 각 1종을 대상으로 MDF를 제조하기 전 原料 纖維의 微細 構造 및 내부결합력 시험 후 MDF의 破壞面에서 纖維表面에 接着劑가 塗布된 형태를 走査電子顯微鏡으로 관찰하였다.

원료 섬유는 針·闊葉樹材 모두 fiber twisting 및 shrinkage fold 등이 관찰되었다. 針葉樹材의 경우는 有緣壁孔部에서 有緣壁孔이 없는 부분에 비하여 shrinkage fold의 발생 빈도가 낮고 表面 剝離는 假導管 중 벽공이 없는 부분에서 관찰되었다. 闊葉樹材 木纖維는 針葉樹材와 마찬가지로 shrinkage fold가 관찰되었으나 表面 剝離는 거의 관찰되지 않았다. 闊葉樹 纖維에서는 벽공의 유무에 따른 shrinkage fold의 差異가 거의 관찰되지 않았는데 이는 木纖維가 針葉樹 假導管보다 작은 單壁孔을 갖기 때문으로 생각된다. 또 放射柔細胞와 假導管및 木纖維의 剝離 部分에는 隆起部가 관찰되었다.

내부결합력 시험후 나타난 파괴면을 통하여 접착제 분포를 관찰한 결과 거의 모든 纖維들이 接着劑로 둘러싸여 있었으며 纖維간 接着形態도 매우 다양하였다. 針闊葉樹材 간에 强度의 차이는 있었지만 破壞 形態는 큰 차이를 나타내지 않았다. 즉 針闊葉樹 모두 接着層이 아닌 纖維에서 破壞가 발생하였으며 섬유에서 剝離된 細胞壁의 일부가 다른 纖維의 表面에 남아있는 형태와 纖維 表面에서 떨어져 나간 형태로 관찰되었다. 세포 구성이 단순한 針葉樹 MDF에 비하여 柔細胞와 導管 및 木纖維의 파편들이 闊葉樹 MDF 에서는 多樣하게 분포하였다.

Keywords : MDF fiber, adhesive, fiber twisting, shrinkage fold, surface loosening, internal bond test, failure site

1. INTRODUCTION

MDF(Medium Density Fiberboard) is a resin-bonded composite pannel. During fiberboard pulp manufacture, wood chips are reduced to individual fibers, fiberbundles and fiber fragments and then reformed into panels with the fibers bond together by synthetic resin. These

*1 접수 1996년 3월 20일 Received March 20, 1996
*2 경북대학교 농과대학 College of Agriculture, Kyungpook National University, Taegu 702-701, Korea

MDF fibers produced by thermomechanical pulping method have unique surface structure which influences many of properties of MDF. Also. adhesive distribution in MDF greatly affects physical and mechanical properties of MDF.

However, there have been a few reports about fundamental properties of the fibers and adhesive distribution in MDF. Koran(1970) studied microstructure of fibers obtained from Bauer pressurized refiner and from Masonite process with light and electron microscope. He reported that fibers produced by Bauer pressurized refiner at 110℃ display rough surface structure with numerous surface fibrillation with intermittent areas of S_2 layer. The fibers produced by Masonite process at 254~298℃ exposes smooth surface structure that consists of a continuous and intact envelope of primary wall.

Butterfield *et al*(1992) studied failure surface of MDF panels fractured during internal bonding and bending strength test with scanning electron microscope. He reported that during IB test, the failure occurred predominantly involved fiber intrawall failure usually at S_1/S_2 interface within the cell walls. During bending strength test, failure was both transwall and intrawll. Intrawall failures, occurred on surface parallel to the dominant fiber plane, while transwall failure of entire fiber was common on the edges of the breakes that were at the right angle to the dominant fiber plane. Myers *et al*(1987) studied fibers produced by refining process using drainage rate, screen classification, pulp composition, fiber dimension and scanning electron micrographs. Myers and Youngquist *et al*(1986, 1987) investigated adhesive distribution in hardboard according to adhesive and forming method using fluorescence and electron microscope.

The objects of this study are investigating surface morphology of MDF fibers and adhesive distribution in MDF by observing failure surface produced by internal bond test. Also, efforts were concentrated on the micromorphological difference of MDF fiber surface and adhesive distribution between conventional MDF made from radiata pine and rubber wood MDF.

2. MATERIALS & METHODS

2.1 Materials

MDF and MDF fibers manufactured from radiat pine(*Pinus radiata*)on which adhesives does not applied was sampled from the MDF manufacuring factory. These fibers was produced by thermomechanical pulping process under the condition of 160~190℃, 8~13 atmospheric pressure. The urea formaldehyde resine was rapidly applied on the fibers in blow line. After flash drying, fibers were formed into mat by air and hot pressed. Sampled MDF has 18mm thickness and 0.7~0.8 specific gravity.

Since MDF made from hardwood was not manufactured domestically, MDF made from rubber wood in Malaysia was used. Thickness is 18mm and specific gravity is 0.67.

2.2 Methods

2.1.1 SEM Observation

Critical point drying was directly conducted on the fibers. For the observation of micromorphology of fiber surface, fibers were delignified with Na_2ClO_3 and vacuum dried. After gold coating, fibers were examined with Hitachi S-4100 SEM at 15kV.

2.2.2 SEM observation of MDF after internal bond test

Internal bond test was conducted following JIS standard. After 50×50mm specimen was prepared, each side of specimen was bonded with epoxy resin on the aluminum block. Then, the tensile strength was loaded on the specimen perpendicular to the surface plane of the specimen with the speed of 1mm/min. Small samples of the failed surface were prepared and examined with the same method in 2.2.1.

3. RESULTS & DISCUSSION

3.1 Micromorphology of MDF fiber

3.1.1 Micromorphology of radiata pine MDF fiber

In general, fibers maintained their original shape, but in Fig. 1, fiber twisting was occurred almost all the fibers and narrow strips and long ribbons of wall layer were delaminated from the fiber surface. In Fig. 2, microfibril orientation was observed distinctly on the delaminated portion of the fiber surface. It would suggested that this delamination may resulted from rubbing action of fibers against one another and against the grooves of the refiner plates.

In Fig. 3, fiber separation was occurred at middle lamella. In Fig. 4, it was observed that the surface of MDF fibers exhibit numerous shrinkage folds that are densely spaced and uniformly distributed over the entire surface. Especially, shrinkage fold was commonly observed at pit-free portion but not at pitted portion. Also, it was observed that most of shrinkage folds

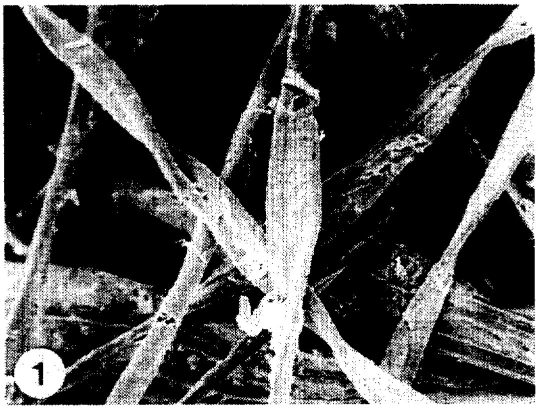

Fig. 1. Softwood MDF fiber at low magnification. Fiber twisting and surface loosening was occurred(×200).

Fig. 2. Outer layer was removed from the fiber surface. Surface loosening was occurred. Arrow(→) shows microfibril orientation (×2,000).

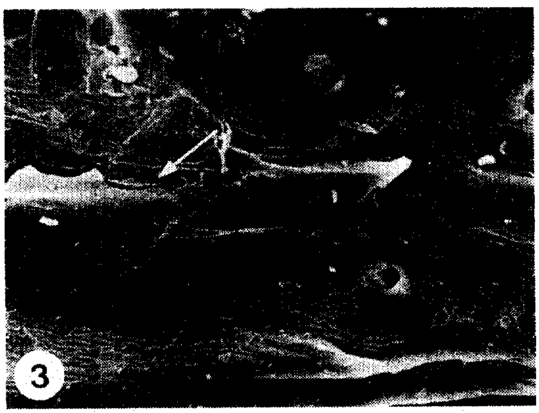

Fig. 3. Fiber separation occurred at middle layer. Arrow(→) shows fiber separation occurred at the middle layer of fibers (×800).

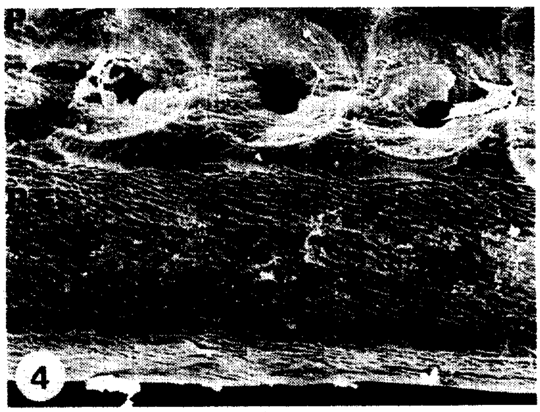

Fig. 4. Shrinkage Fold on the radiata pine MDF fiber surface. Note that difference of shrinkage fold between pitted wall and pit-free wall. (P : Pitted wall, PF : Pit-free wall ; ×800)

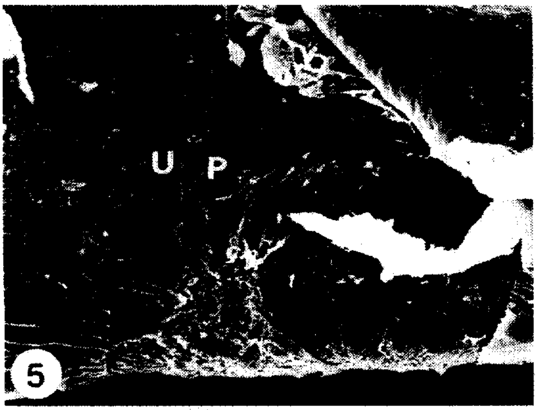

Fig. 5. Difference of fiber surface between intact fiber surface and delaminated fiber surface (U: Intact area, P: Delaminated area : ×1,000).

appear to be parallel with the microfibrilar orientation in S_2 layer. Atchison *et al* suggested that these shrinkage folds are caused by the lost of polysaccharide in the cell wall during thermomechanical pulping.

Delaminated portions on the fiber surface were different from the portions where delamination was not occurred. While delaminated sites on the fiber appeared mostly in pit-free portion and observed small cracks along the microfibril orientation, the portions where delamination was not occurred distributed mostly in pitted wall and showed little or no shrinkage fold.

Fig. 7. Ridges(←) at ray contact area (×1,000).

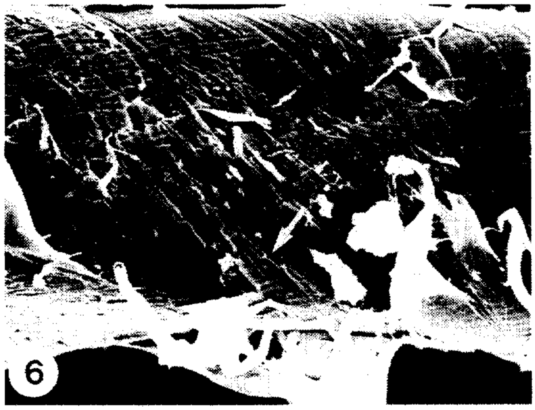

Fig. 6. Delaminated surface shows microfibril orientation(↔). Also, cracks(←) were shown (×1300).

Fig. 5 and 6 is surface structure of MDF fiber after delignifying with Na_2ClO_3. In Fig. 5 differences between intact fiber surface and delaminated fiber surface was shown. In Fig. 6 microfibril orientation was evident and fine cracks were observed along the microfibril orientation. This would suggest that delamination occurred between primary wall and secondary wall or between S_1 and S_2 layer in secondary wall. In Fig. 7, horizontal ridges of ray middle lamella was observed at ray contact area.

3.1.2 Micromorphology of rubber wood MDF fiber

Same as radiata pine MDF fiber, rubber wood MDF fiber maintains their original shape, but surface loosening was not observed.

In Fig. 8, fiber twisting and shrinkage fold were occurred almost all the fibers. In Fig. 9, small pharenchymas were distributed among the fibers. In Fig. 10, unlike in radiata pine fiber, difference between pitted portion and pit-free portion was not evident. In Fig 11, same as in radiata pine fiber, ray contact area has horizontal ridges of ray middle lamella. Table 1 shows differences of features between radiata pine and rubber wood MDF fibers.

Overall surface morphology of radiata pine and rubber wood fiber were intact but in radiata pine fiber, surface delamination was distinct. Both in

Fig. 8. Hardwood MDF fiber at low magnification. Fiber twisting was occurred (×400).

Fig. 9. Parenchyma remained on fiber or between fibers (P: Axial parenchyma, RP: Ray parenchyma: ×800).

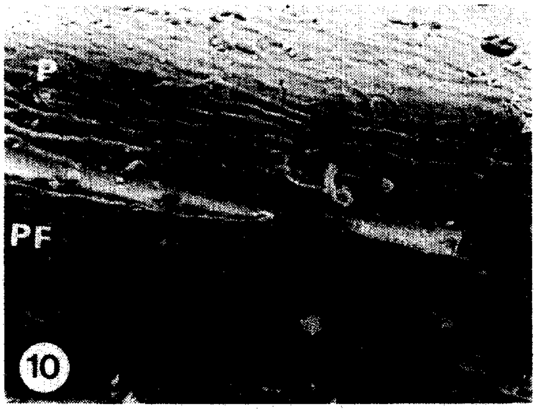

Fig. 10. Shrinkage fold on pitted wall and pit-free wall (P: Pitted wall, PF: Pit-free wall: ×3,000).

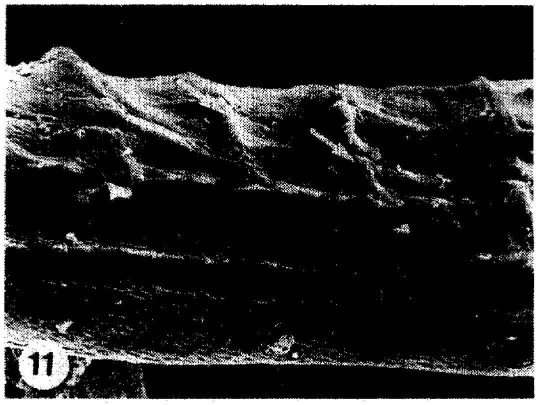

Fig. 11. Ridges(←)on fibers at ray contact area (×1,100).

Table 1. Differnces of features between radiata pine and rubber wood fibers for MDF.

Features		Softwood fiber	Hardwood fiber
Overall Surface Structure		Almost intact	Almost intact
		Surface loosening	No Surface loosening
Fiber Twisting		Distinct	Distinct
Shrinkage Fold		Distinct	Distinct(partially)
Micromorphology of Fiber Surface	Pitted Area	Distinct shrinkage fold Surface loosening Exposure of inner layer	Shrinkage fold No surface loosening
	Pit-free Area	Little shrinkage fold Little surface loosening	Very little differences between Pitted wall and Pit-free wall
	Ray Contact Area	Little shrinkage fold Ray middle lamella ridge Little Shrinkage fold	Little shrinkage fold Ray middle lamella ridge Shrinkage fold

Fig. 12. Morphological features of fiber and adhesives after internal bond test. Fibers were encrusted with adhesives (×400).

Fig. 13. Fiber contact area where the adhesion occurred. Arrow(→) shows that adhesion site was fractured after internal bond test (×2,000).

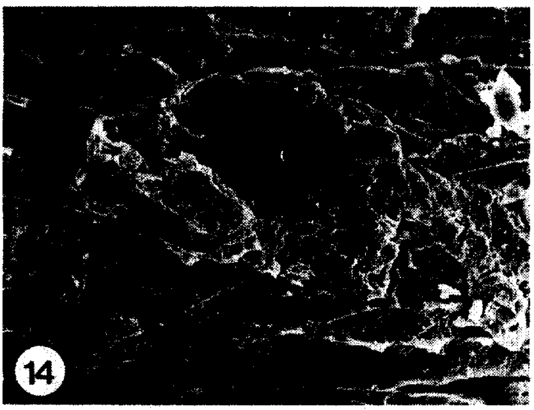

Fig. 14. Conglomerated adhesives on fiber (×1,500).

Fig. 15. Fibers encrusted with adhesives. Arrows(→) show that some bordered pit was blocked with adhesives (×1,000).

radiata pine and rubber wood fiber, fiber twisting and shrinkage fold was evident. In radiata pine fiber, differences in shrinkage fold and surface fibrillation between pitted portion and pit-free portion was observed while in rubber wood fiber, little differences between pitted portion and pit-free portion was observed. Both in radiata pine and rubber wood fiber, horizontal ridges of ray middle lamella were observed.

3.2 Observation of MDF fracture site after IB test

During internal bond test, the failure occurred parallel to the surface and at the core of MDF which has lower density than surface. Internal bond strength was the highest in MDF that was made from radiata pine only, MDF made from mixed (radiata pine + waste softwood), MDF made from waste wood only is the third and rubber wood MDF is the lowest. The average internal bond strength is 6.9kg/cm^2 in radiata pine MDF and 5.4kg/cm^2 in rubber wood MDF.

3.2.1 Observation of radiata pine MDF fracture site after IB test

It was observed that some fibers maintain their original shape but others are transformed like flat tube shape. All the fibers were ran-

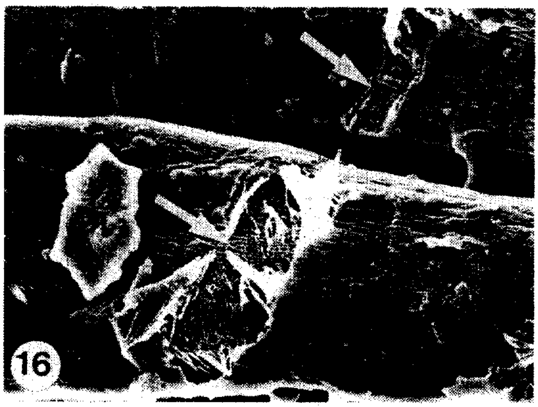

Fig. 16. Delaminated wall portion was shown on the fibers. Arrows(→) show that part of fiber surface was removed from the fiber (×1,000).

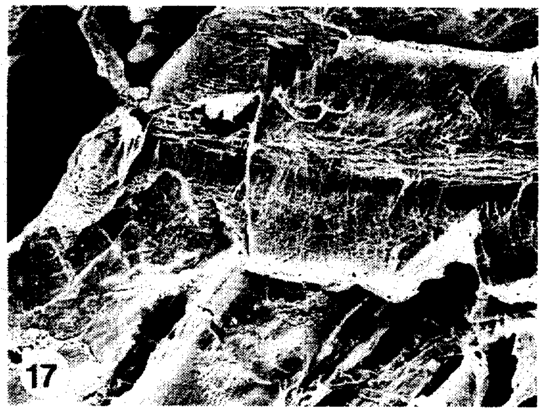

Fig. 17. Delaminated wall portion(←) was remained on the other fibers (×1,000).

domly entangled. In Fig. 12, adhesives which entirely or partially encrusting fibers were observed but the thickness of adhesives were not even one.

The morphology of adhesives and adhesion were varied : in Fig. 13, adhesion was primarily occurred where fibers encrusted with adhesives were contact each other. In Fig. 14, conglomerated adhesives which seems not involving in adhesion were observed.

In Fig. 15, shrinkage fold was observed faintly because of adhesives on the fiber surface and some of bordered pit was blocked with adhesives. It was assumed that some of adhesives penetrate through bordered pit and cross field but was not confirmed.

Failures in adhesion sites were typified by depressions in the fiber walls at the site of the resin bridge caused by the loss of wall material to the separated fiber and by portions of wall material from the separated fiber left attached to the resin bridge. In Fig. 16, primary wall and part of secondary wall separated from the fiber surface and in Fig. 17, fiber wall fragments of separated fiber left attached on the other fiber. Failure was predominantly occurred at the fiber surface rather than at the adhesion layers.

3.2.2 Observation of rubber wood MDF fracture site after IB test

As in the radiata pine MDF fibers, rubber wood MDF fibers maintain their original shape and some other fibers are transformed into flat tube shape and these fibers were randomly entangled.

Fibers were entirely or partially encrusted with adhesives and thickness of these adhesives were varied. In Fig. 18, shrinkage fold was observed even though the fiber was encrusted with adhesives and some of simple pit was blocked with adhesives. Micromorphology of adhesive was varied : looks like patches and

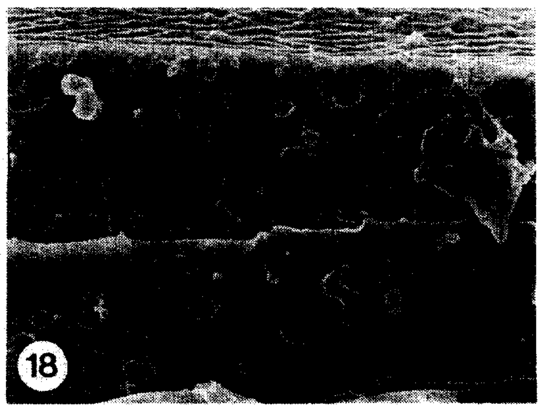

Fig. 18. Hardwood MDF fiber was encrusted with adhesives. Some of simple pits were blocked with adhesives (×2,000).

Fig. 19. Fiber contact area where the adhesion occurred. Arrow(→) shows adhesion site (×2,000).

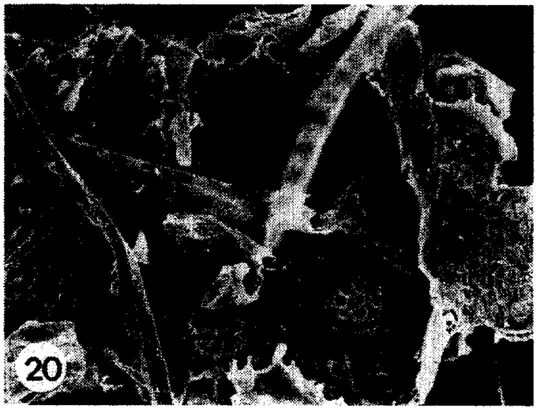

Fig. 20. Fragment of vessel among the fibers (×300).

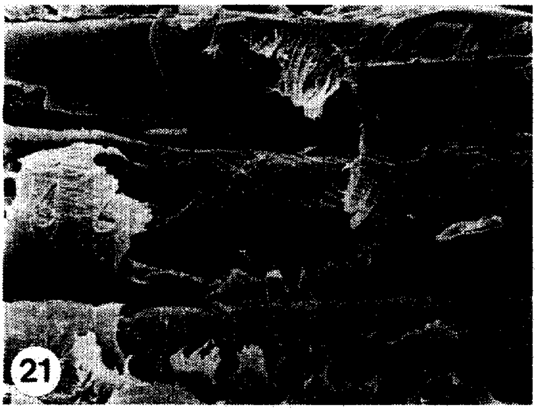

Fig. 21. Delaminated wall portion was shown on the fibers. Microfibril orientation was shown (×1,500).

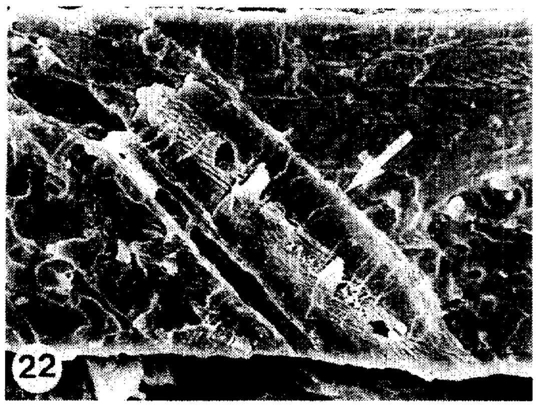

Fig. 22. Fiber fragment(←) remained on the other fiber (×1,500).

Table 2. Differences of features between radiata pine and rubber wood MDF breakage area after internal bond test.

Features	Softwood MDF	Hardwood MDF
Average IB Strength	6.9kg/cm^2	5.4kg/cm^2
Fiber Morphology	Disorderly weaved Intact or partially flat Few fiber fragments	Disorderly weaved Intact or partially flat Many fiber fragments (Vessels, Parenchymas, etc)
Adhesives on Fibers	Varied (Encrust, Conglomerate etc)	Varied (Encrust, Conglomerate etc)
Micromorphology of Breakage Area	Fiber surface fragments were attached and/or delaminated on fiber surface	Fiber surface fragments were attached and/or delaminated on fiber surface

conglomerated shape. In Fig. 19, adhesion site between two fibers in MDF was shown. In Fig 20, vessels were broken apart and formed a large plate-like adhesion site.

Failures at the adhesion site were typified by depressions in the fiber walls at the site of the resin bridge caused by the loss of wall material to the separated fiber and by portions of wall material from a separated fiber left attached to the resin bridge. Same as radiata pine MDF, fracture was occurred not at the adhesives but at the fibers. In Fig 21, thin lamella was removed from the fiber surface and microfibril orientation of S_2 layer was shown. Part of pharenchymas and vessel fragments were observed among the fibers.

Table 2 shows differences of features between radiata pine and rubber wood MDF fracture site produced by internal bond test.

There are little micromorphological differences between radiata pine and rubber wood MDF fracture site produced by internal bond test. Internal bond strength of radiata pine MDF was higher than rubber wood MDF and in hard wood MDF. Also, a lot of broken fibers such as vessel fragments and pharencymas was observed in rubber wood MDF. During internal bond test, failures occurred predominantly at the fiber and fracture site was typified by delamination and attachment of fiber wall fragment.

4. CONCLUSION

Micromorphology of radiata pine (radiata pine, ***Pinus radiata***) MDF and rubber wood (rubber wood, ***Hevea brasiliansis***)fibers obtained from thermomechanical pulping process was observed using SEM. Also, adhesive distribution in MDF was investigated by observing failure surface of MDF caused by internal bond test. Both rubber wood and radiata pine MDF have fiber twisting and shrinkage fold. In radiata pine MDF fiber, less shrinkage fold and surface loosening were observed at pitted portion than pit-free portion. In rubber wood MDF fiber, shrinkage fold was observed like radiata pine fiber but, surface loosening was not observed. Also, there is no difference in shrinkage fold between pitted portion and pit-free portion. It was supposed that in radiata pine MDF fiber, big bordered pit prohibited occurring of shrinkage fold but, in rubber wood MDF fiber, smaller simple pit couldn't.

Both in radiata pine and rubber wood fiber, horizontal ridges of ray middle lamella was observed at which tracheid and wood fiber - ray contact area.

Investigation of fractured surface produced by internal bond test of MDF revealed that most fiber was completely or partially encrusted with adhesives and morphology of adhesive distribution was varied. Although, internal bond strength was higher in radiata pine MDF, failure of radiata pine and rubber wood MDF was occurred not at the glue line but at the fiber surface and feature of failure was similar to each other. Two types of fractured site was observed : surface with thin fiber wall fragment delaminated from the fiber surface and surface with remaining fiber fragment.

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