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Original

Production Technology for Acetylated Low-density Particleboard (II)[*1]

Decay and Termite Resistance[*2]

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Abstract——Low density particleboards made from control and acetylated chips at 17 percent acetyl weight gain using isocyanate adhesives, were subjected to standard decay tests, to bending-creep tests under fungal attack, and to termite tests.

The rate of decay was slow in the boards containing 50 percent of acetylated chips causing smaller weight losses and reduced thickness swelling as compared to controls after exposure to fungal attack. The specimens containing 100 percent of acetylated chips showed no sign of decay. When exposed to fungal attack in bending-creep tests, the blended particleboards of higher specific gravity maintained their strength longer than untreated controls, but all untreated specimens and blended boards of lighter specific gravity failed within a short time span. Acetylated boards containing 100 percent of treated chips showed little strength reduction after 100 days and very little additional deflection was seen after longer exposure.

Though the weight losses by termite feeding were not so large as controls, acetylated boards were able to be attacked by the termite of *Coptotermes formosanus*. However, they were hardly attacked by *Reticulitermes speratus*.

1. Introduction

Extensive research has been conducted on dimensional stability and biological resistance of acetylated solid wood, but little effort has been put forth to apply this chemical modification principles to reconstituted wood products, such as particleboards. Arora et al.[1] treated thin slices or particles from five species with acetic anhydride vapor catalyzed with piridine, and produced particleboards. The acetylated particleboards showed improved dimensional stability and mycological resist-

*1 Report I: Mokuzai Gakkaishi (in press).

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ance. Nishimoto and Imamura[2] made particleboards from mixtures of control and acetylated spruce chips, and they indicated lower thickness swelling after immersion in water and resistance to decay and termite attacks could be attained as the amount of acetylated chips increased. Recently, Rowell et al.[3~5] developed a simple dip acetylation process that has been applied to the acetylation of wood flakes. Flakeboards made from dip acetylated flakes have been proved to have greatly improved dimensional stability to both liquid water and water vapor, and high resistance to wood-destroying microorganisms.

On the other hand, low density particleboards bonded with isocyanate compound adhesives were recently developed[6]. The remarkable features of these boards include their high internal bond strength in spite of low density and their high dimensional stability. Low density particleboards made of acetylated chips are predicted to have higher dimensional stability originating from low density of board manufacture and chemical modification of raw materials, and improved resistance to decay and termite attacks.

Particleboards with moisture and biological resistance would have potential application in numerous uses such as some exterior or constructional panels under severe conditions.

The purpose of the present research was to determine the resistance of low-density acetylated particleboards against decay fungi and termites. High dimensional stability and improved mechanical strength in wet condition have been discussed in the previous report[7].

2. Materials and Methods

2.1 Reaction of chips and board production

Wood chips with an average thickness of 0.5 mm were prepared from seraya (Shorea spp.) residue from peeler logs with air-dry specific gravity of 0.5 using a drum flaker. They were followed by hammer-milling into strand-type particles with an average length of 17.3 mm and width of 1.4 mm.

The chips were oven dried and impregnated with sodium acetate as a catalyst at 2 percent of target retention based on weight of the dry chips. They were again oven dried, and after which transferred to a stainless steel vessel and impregnated with acetic anhydride. Acetylation was carried out for a required period of 10 minutes at 120–130°C. Then, after unreacted acetic anhydride and by-product acetic acid were removed, reacted chips were rinsed in water until the smell of acetic acid was undetected. The chips were then dried with hot air. The acetylated chips were obtained at percent weight gain (observed acetylation rate) of 17 percent.

The untreated chips were air dried to about 12 percent of moisture content, and acetylated ones of less hygroscopic were conditioned at 8 percent of moisture content in the high humidity chamber. Untreated chips, acetylated chips, and blended chips from 50 percent untreated/50 percent acetylated were pressed into low density particleboards using isocyanate resin. Adhesive of isocyanate resin (UL 4800 formulated by Gun-ei Kagaku Kogyo Co. Ltd.) was sprayed to chips at 10 percent of resin solid content based on weight of the dry chips. All boards were made in a 350×400 mm size and 12 mm thickness, by pressing for 3.5 minute at 160°C. Two levels of specific gravities of each composition were intended at 0.4 and 0.5, and an appropriate weight of chips was used to attain those.

2.2 Decay test methods

To evaluate decay resistance of untreated and acetylated particleboards, two test methods were employed; one was a standard decay test based on weight losses after a certain period of time, and the other was a bending creep test under progressive fungal attack.

Decay tests were run according to JWPA (Japan Wood Preserving Association) Standard No. 3–1979. Square samples (25 mm wide) of test boards were sterilized and placed in glass-jars containing a brown-rot fungus *Tyromyces palustris* (Berk. et Curt.) Murr. or a white-rot fungus *Coriolus versicolor* (L. ex Fr.) Quél. Specimens were removed after 12 weeks, and extent of fungal attack was determined based on weight loss. Thickness swelling and moisture content of each board at the end of decay test were also estimated.

Standard decay testing uses weight losses of samples in evaluation of results. However, as has been stressed in some papers[8,9] evaluation of resistance based on reduction of strength properties is more practical to particleboard's intended use, where strength losses can be high even at low weight losses.

For investigation of the strength reduction of particleboards, specimens were subjected to bending creep tests under progressive fungal attack in the decay chamber designed by the authors[10]. The outline of the test method was described as follows. The chamber consisted of a metal-wire frame, covered with a polyethylene bag and a porous plug of silicon rubber. The brown-rot fungus *T. palustris* was used as a rotting agent. Mycelial fragments prepared from shake culture were spread on the bottom tension surfaces of the sterilized particleboards. A tray filled with sterilized water was set at the bottom of the chamber to keep the specimen (50 by 350 mm) in a humid condition. Weight was applied at the center of span (300 mm) of specimen from outside of the decay chamber. The weight was fixed at the value which caused 1 mm initial deflection. Deflection of the board at the center of the span was measured regularly with electric dial gauge. Bending creep tests were carried out until particleboard specimens failed or for 100 days in a conditioning room at 26°C suitable for the incubation of the fungus. After failure or 100 days, oven-dry weight loss was determined for each specimen.

2.3 Termite test methods

For evaluation of termite resistance, two test methods were employed. A forced-feeding test was used where treated or untreated board was the only source of nutrient for the termites according to the JWPA Standard (No. 11, 1981). The individual test specimen (25×25 mm×board thickness together with 150 sound workers and 15 soldiers were put in a cylindrical, clear plastic container (inside dimension, 8 cm in diameter and 6 cm in height) having the bottom sealed with hard plaster of Paris. The plastic containers were placed in a large covered case which had moist cotton wool at the bottom to keep the test sets in high humidity condition. After a 21 days test duration, the number of dead termites was recorded. The test specimens were then removed to calculate the percent weight loss.

The other method was a choice feeding test in which specimens were placed randomly on the breeding nest of termites for a period of 30 days. Percent weight loss was calculated after cleaning off surface debris and oven drying. Two termite species, *Coptotermes formosanus* Shiraki and *Reticulitermes speratus* Kolbe, were employed for the tests.

3. Results and Discussion

3.1 Decay resistance of particleboards

Results of decay tests are shown in Table 1. Effect of acetylation of chips on decay weight loss of particleboards is most evident for the boards fully composed of acetylated chips for both a brown-rot fungus and a white-rot fungus. For example, control boards of 0.4 specific gravity suffered a 26.5 percent weight loss from attack by *T. palustris*, while acetylated samples lost only 0.5 percent weight. For

Table 1. Average weight loss in decay tests for particleboards exposed to *Tyromyces palustris* and *Coriolus versicolor* for 12 weeks

Board type		Average weight loss*	
Content of acetylated chips (%)	Specific gravity	*T. palustris* (%)	*C. versicolor* (%)
0	0.4	26.5	35.6
	0.5	20.8	30.6
50	0.4	13.7	20.8
	0.5	14.1	16.9
100	0.4	0.5	0.1
	0.5	0.2	0.0

* Average of 9 specimens.

C. versicolor, acetylated boards exhibited higher resistance. The blended particleboards of untreated and acetylated chips were decayed in lesser weight losses as compared with untreated boards indicating that acetylated chips were left without attacks by decay fungi.

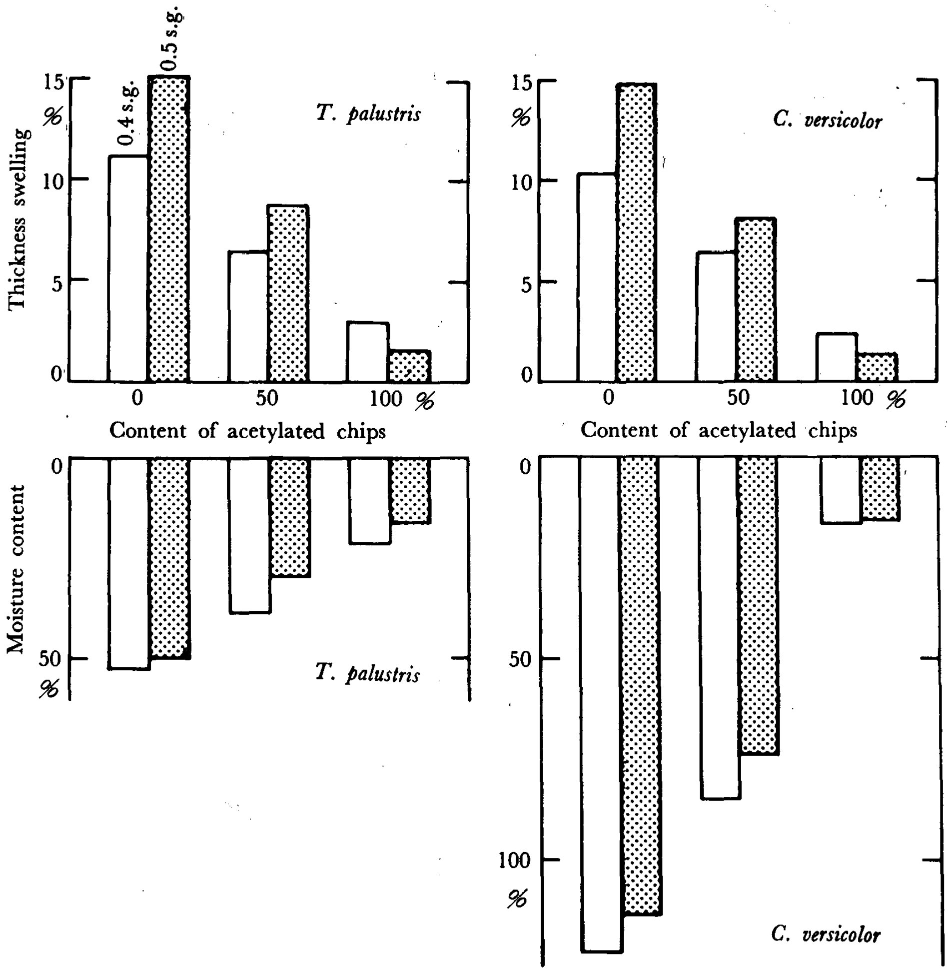

Fig. 1. Thickness swelling and moisture content of particleboards after exposure to fungal attack for 12 weeks by decay tests.

The effect of acetylation on thickness swelling caused by decay fungi can also be seen (Fig. 1). With blending acetylated chips at 50 percent, thickness swelling was reduced up to 60 percent as compared to untreated boards. The fully acetylated boards underwent much less thickness swelling after 12 weeks fungal attack. The reason for reduced thickness swelling of acetylated boards may be due to lesser water absorption and to a small loss of inner bonding owing to high resistance to fungal attack.

The other result worthy of mention is the reduced moisture content of test boards after exposure to decay fungi. Boards of 100 percent content of acetylated chips lowered moisture content to under 20 percent for *T. palustris* and 15 percent for *C. versicolor* (Fig. 1). The control boards, on the other hand, showed moisture content of 50 percent for *T. palustris* and about 120 percent for *C. versicolor* as much as generally observed in decayed wood.

In bending creep tests under significantly small weight of loading, the deflection-time curves normally become stable when degradation of specimens does not occur. If remarkable increasing of deflection is detected, it is assumed to be due to the reduction of mechanical properties caused by the action of decay fungi, and the time to the occurance would vary depending to the durability of the test specimens.

In the mechanical tests of the duration of stress, the fixed weight is generally determined in a certain stress ratio relative to the static strength. However, the strength values in standard mechanical tests are individually different among each specimen and difficult to be estimated non-destructively. Incidendally modulus of rupture is proved to be proportional to modulus of elasticity. In the bending creep test employed for evaluation of decay resistance, the weight was fixed at the value which caused 1 mm initial deflection being equivalent to 1/300 of span length. The average value of fixed weight is shown in Table 2. The values of loading stresses ranged 6.3–15.8 kg/cm^2 indicating that acetylated particleboards could carry larger weight than untreated controls. All of them, however, were included among 10–15 as a percent of the average static bending strength measured with the adjacent specimens.

Table 2. Average values of fixed weight, period of test duration until creep fracture and weight loss of specimens in bending creep tests under decay

Board type		Fixed* weight (kg/cm^2)	Duration period (days)	Weight loss (%)
Content of acetylated chips (%)	Specific gravity			
0	0.4	7.5	18	8.5
	0.5	13.1	12	5.2
50	0.4	6.3	15	5.0
	0.5	12.5	32	8.8
100	0.4	12.4	—**	0.3***
	0.5	15.8	—**	0.5***

* Bending stress which caused initial deflection of 1 mm after inoculation of decay fungi. ** Not fractured for more than 100 days. *** Weight loss after test period of 100 days.

Deflection-time curves for control and acetylated particleboards are shown in Fig. 2 representing one of three replicates. These curves express time as a loga-

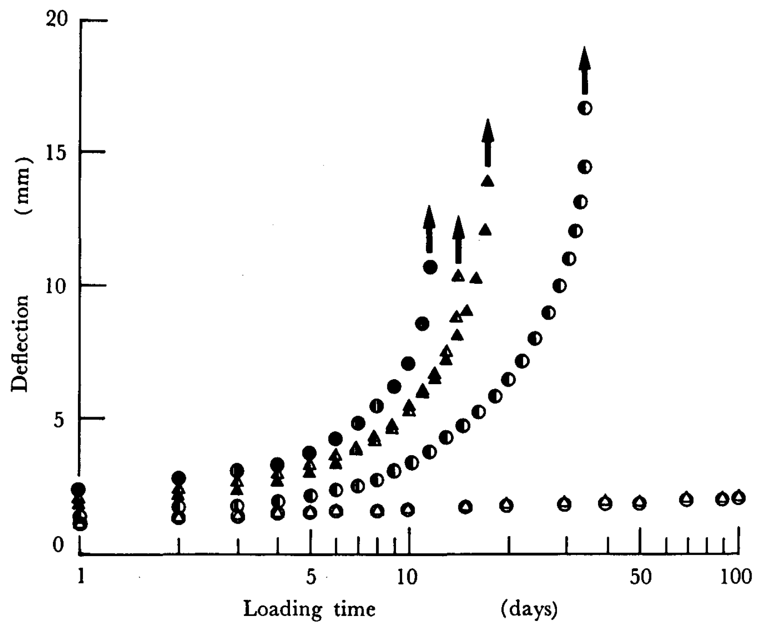

Fig. 2. Deflection-time curves of particleboards in bending-creep tests under progressive fungal attack by *Tyromyces palustris*.
Note: ●▲; Untreated controls, ○△; 100% acetylated, ◐◭; 50% untreated and 50% acetylated. ▲◭△; 0.4 s.g., ●◐○; 0.5 s.g. Fracture of test board is shown by arrow.

rithm. There is an initial increase of deflection for all types of particleboards, then a stable stage and finally, for control and blended boards a steep slope to failure. Control particleboards of 0.4 specific gravity failed in an average of 18 days, and 12 days for boards of 0.5 specific gravity. After failure, weight losses averaged 8.5 and 5.2 percent respectively.

Blending of acetylated chips had no effect on the tolerance of boards of 0.4 specific gravity against fungal attack, but blended particleboards of 0.5 specific gravity maintained their strength longer than untreated control boards. The boards of 0.5 specific gravity are more densely packed than lighter boards, and they swell a little in thickness when blended of acetylated chips. It is supposed that the fungal invasion into the inner part of boards take more time for the boards of higher specific gravity.

Particleboards made of acetylated chips showed only a very small deflection after 100 days and neglegible weight losses at the end of this time. The test was continued for 100 additional days and very little additional deflection was seen.

Mycelium colonization fully covered the surfaces of control boards within one week, but the extent of mycelium development was significantly slower in blended boards of 0.5 specific gravity. Acetylated particleboards showed a little colonization on the surfaces but the fungi could not attack the acetylated chips, so little weight was lost.

3.2 Termite resistance

As shown in Tables 3–5, blended and fully acetylated boards were superior to untreated controls in limiting ingestion of both *C. formosanus* and *R. speratus.* Al-

Table 3. Weight loss and termite mortality in forced-feeding tests for particleboards exposed to *Coptotermes formosanus* for 3 weeks

Content of acetylated chips (%)	Specific gravity	Weight loss* (%)	Final* termite mortality (%)
0	0.4	4.7	16
	0.5	3.5	20
50	0.4	3.2	27
	0.5	2.4	25
100	0.4	1.7	42
	0.5	1.2	48

* Average of 3 specimens.

Table 4. Weight loss and termite mortality in forced-feeding tests for particleboards exposed to *Reticulitermes speratus* for 3 weeks

Content of acetylated chips (%)	Specific gravity	Weight loss* (%)	Final* termite mortality (%)
0	0.4	4.2	33
	0.5	3.9	36
50	0.4	2.0	55
	0.5	1.8	62
100	0.4	0.2	100
	0.5	0.1	100

* Average of 3 specimens.

Table 5. Weight loss in choice feeding tests for particleboards exposed for one month to *Coptotermes formosanus* or *Reticulitermes speratus*

Board type		Weight loss*	
Content of acetylated chips (%)	Specific gravity	*C. formosanus* (%)	*R. sparatus* (%)
0	0.4	8.4	12.6
	0.5	7.2	9.1
50	0.4	3.2	2.2
	0.5	2.8	1.1
100	0.4	1.0	0.0
	0.5	1.0	0.0

* Average of 3 specimens.

though *C. formosanus* was able to attack acetylated boards, loss in volume was significantly small when compared to controls. In contrast, *R. speratus* could hardly attack acetylated boards leaving only nibbling marks. The difference of feeding by two kinds of termites was more evidenly shown when a choice was available.

In control sets of the forced-feeding tests, the termites survival were over 80 and 60 percent for *C. formosanus* and *R. speratus* respectively; the matching percentages for acetylated specimens were below 60 percent and 0 percent, respectively. It has been pointed out that acetylated wood is eaten by the termites and taken into their intestines, but it is not decomposed by the symbiotic protozoa[11]. As a result, the termites could not obtain nutrient from the breakdown of the acetylated wood. Acetylation is said to have the effect of enhanced starvation, and *R. speratus* is shown to be weaker in starvation than *C. formosanus*.

4. Conclusions

Low density particleboards made of acetylated chips with about 17 percent acetyl weight gain were very resistant to attack by brown- and white-rot fungi. It was also found that acetylated boards were resistant to attack by subterranean termites.

The biological resistance using non-toxic chemicals and greatly improved dimensional stability will lead to the development of new technology of high-performance particleboards.

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