Original

Physical Properties of Low-density Particleboard*[1]

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Abstract——Low-density particleboards bonded with an isocyanate compound adhesive were produced in a full-scale size and their physical properties were examined. The density of the raw materials (*Shorea* spp.) was 0.4 g/cm^3 and those of the boards 0.3–0.5 g/cm^3. Therefore, the compaction ratios of the boards were in the range of 0.75–1.25. The results obtained are as follows; 1) Bending strength in dry condition of boards with air-dry density 0.4 g/cm^3 was 100 kg/cm^2 which is higher than that of Type 100 particleboard defined by JIS A-5908. This can be much improved by overlaying veneers on the particleboard. 2) Internal bond strength of boards was relatively high, in spite of the low compaction ratios. 3) High dimensional stability both in the plane and in the thickness directions of board was obtained on account of the low compaction ratio and the high water resistivity of the adhesive.

1. Introduction

A rapid decrease in the recent supply of peeling logs induces the development of new type substitute panels for plywood such as oriented strand board, waferboard, etc. However, these panels have higher density and less water resisting quality than plywoods, though their comparable strength.

Use of urethane adhesive may bring a possibility in reducing density and swelling of these panels without radical reduction of the strength properties. Recently, one of our co-researchers developed a new formulation of isocyanate compound adhesive which has the technical properties suitable for the production of low-density particleboard.

This paper concerns the fundamental physical properties of low-density particleboard in the density range of 0.3–0.5 g/cm^3. Especially, the dimensional stability is discussed in detail.

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2. Experimental

Raw materials used were Seraya (*Shorea* spp.) end logs and core bolts with air-dry density 0.4 g/cm^3. Strand-type particles were prepared with a drum-flaker and then with a hammer-mill, and they were conditioned to 13 percent moisture content. The average dimensions of the particles were of 13 mm in length, 1.6 mm in width, and 0.6 mm in thickness.

The adhesive used was an isocyanate compound adhesive, UL-4800, formulated by Gun-ei Kagaku Kogyo Co. Ltd. Particles were put into a drum-type rotary blender and were mixed with the resin by means of an airless spray. The resin content was 10 percent on the resin solids per dried particle weight ratio basis. Twenty percent acetone per resin solids weight was added to the resin in order to reduce its viscosity.

Hand-formed particle mats were pressed at 160°C. Both top and bottom surfaces of the mat was covered with glass-fiber reinforced Teflon sheets so as to prevent the mat from sticking to the platens. The "two-steps" pressing procedure was employed for the particleboards of 0.4 and 0.5 g/cm^3 in air-dry density in order to controll the density gradient through the thickness; in the first step, the particle mat was compressed to a thickness less than the target in order to obtain higher density layers near the surfaces. In the second step, the pressure was once released so that the thickness of the compacted mat recovered to that of the thickness bars whcih were inserted soon after the pressure release. For the board with density 0.3 g/cm^3, the conventional pressing method was used in order to obtain homogeneous density profile in the thickness direction of the board.

Table 1. Press schedule used in the experiment

Kind of board		The first step		The second step	
Density (g/cm^3)	Thickness (mm)	Pressure (kg/cm^2)	Time (sec)	Pressure (kg/cm^2)	Time (sec)
0.3	30	—	—	10	480
	40	—	—	10	720
0.4	30	15	30	4	450
	40	15	40	4	680
0.5	40	25	40	15	680

Table 1 shows the pressures and the pressing time at the first and the second step of hot-pressing for various board thickness and density taken in this experiment. The total pressing times were 8 and 12 minutes for the boards with the thickness of 30 and 40 mm, respectively. A preliminary experiment showed that the core temperature of the board rose to 100°C, before the pressing procedure was finished.

Two boards with the dimensions of $1900 \times 980 \times 30$ and 40 mm were produced for each level of board density. Further, veneer-overlaid particleboards in the density range of 0.3–0.4 g/cm^3 were produced with the simulataneous pressing operation.

In comformity to the standard, JIS A-5908, the mechanical and the physical properties of the low-density particleboards were measured. These were modulus of elasticity (*MOE*), modulus of rupture (*MOR*), internal bond strength, and screw withdrawal resistance in air-dry condition, *MOR* and *MOE* after 2 hrs boiling followed by 1 hr water soak at 25°C and thickness swelling after 24 hrs water soak at 25°C. The span used in the bending strength test was 30 times as long as the board thickness to eliminate the influence of the horizontal shear. Besides these standard tests, special measurements were made on the thickness swelling in continuous water-immersion

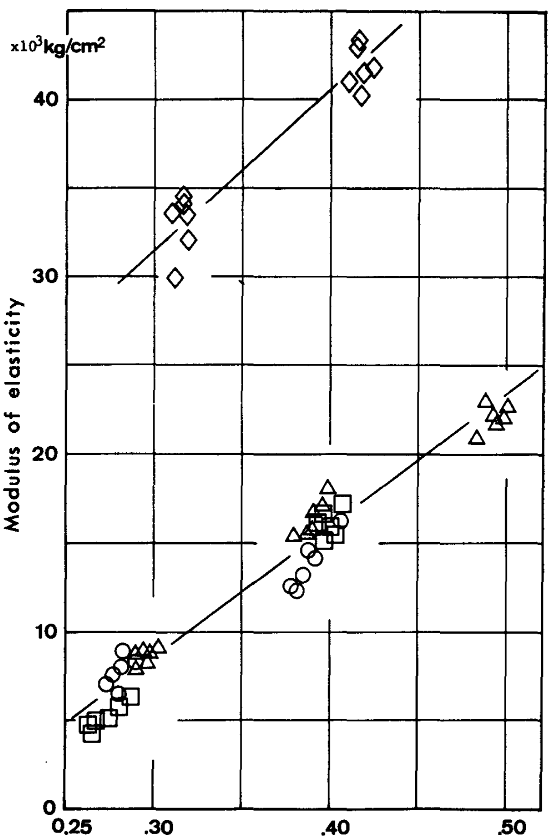

Fig. 1. Modulus of elasticity in bending of dry condition as a function of board density

Kinds of board	From end log		From core bolts	Veneer-overlaid
Symbols	○30	△40	□30	◇30

Numbers indicate the board thickness in mm.

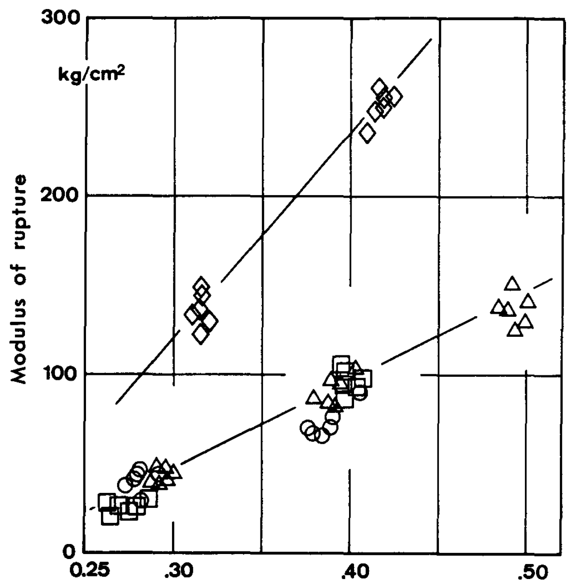

Fig. 2. Modulus of rupture in bending of dry condition as a function of board density

Kinds of board	From end log		From core bolts	Veneer-overlaid
Symbols	○30	△40	□30	◇30

Numbers indicate the board thickness in mm.

at 25°C and in dry-soak repetition in order to investigate the dimensional stability. The condition of dry-soak repetition was 24hrs dry in an oven at 60°C and 24hrs soak in water at 25°C. The linear expansion was also measured with the specimens of wet-bending test of which condition was 2hrs boiling and then 1 hr water soak at 25°C.

3. Results and Discussion

Fig. 1 and Fig. 2 show the relation of *MOE* and *MOR* in dry bending to the board density, respectively. Both the *MOE* and the *MOR* increase linearly with an increase of board density, and are independent of the raw materials and the board thicknesses used in this experiment. The *MOE* and the *MOR* of the non-overlaid boards with the air-dry density of 0.4 g/cm³ are around 17×10^3kg/cm² and 100 kg/cm², respectively. These values are higher than those of Type 100

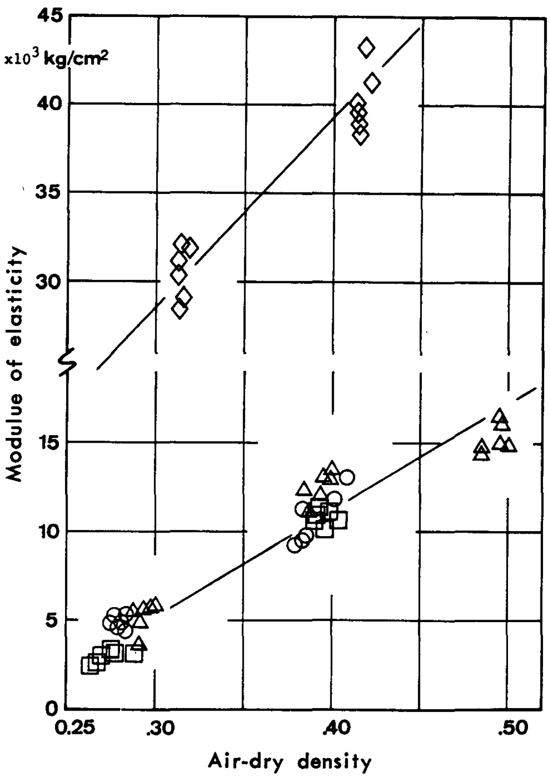

Fig. 3. Modulus of elasticity in bending of wet condition as a function of board density

Kinds of board	From end log	From core bolts	Veneer-overlaid
Symbols	○30 △40	□30	◇30

Numbers indicate the board thickness in mm.

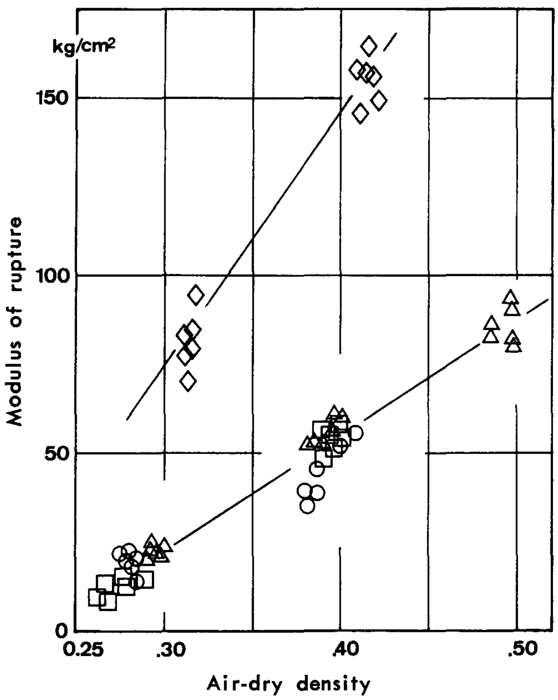

Fig. 4. Modulus of rupture in bending of wet condition as a function of board density

Kinds of board	From end log	From core bolts	Veneer-overlaid
Symbols	○30 △40	□30	◇30

Numbers indicate the board thickness in mm.

particlaboard in the classification of JIS standard, but still do not meet sufficiently the requirements in structural use. However, this can be simply covered by use of thicker boards: when comparing at a same weight, the bearing load of low-density particleboard with density 0.4 g/cm^3 is much higher than that of ordinary particleboards with density 0.8 g/cm^3 and half thickness. The *MOE* and the *MOR* of veneer-overlaid particleboard in the face grain direction were much improved, as shown in the figures. Further stduies are necessary on the effects of particle shape and machine type for its preparation on the bending properties, which are now proceeding.

Fig. 3 and Fig. 4 show the relation of *MOE* and *MOR* in wet bending to the board density, respectively. The similar relationships are observed to those in Fig. 1 and Fig. 2. The retention of the *MOR* is around 60%, while that of the *MOE* around 70%. It is noteworthy that the retention of *MOE* of veneer-overlaid particleboard shows more then 90%.

Fig. 5 shows the internal bond strenght of the low density particleboards in

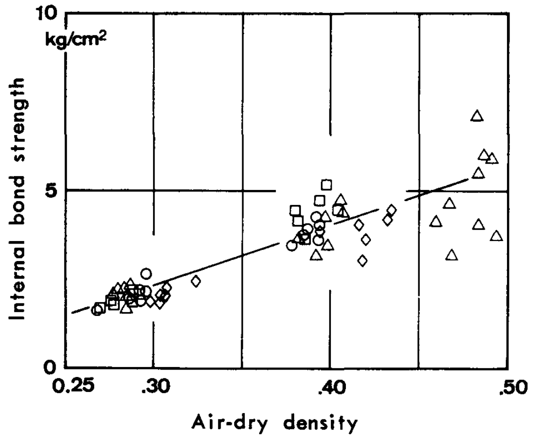

Fig. 5. Internal bond strength in relation to the board density

Kinds of board	From end log	From core bolts	Veneer-overlaid
Symbols	○30 △40	□30	◇30

Numbers indicate the board thickness in mm.

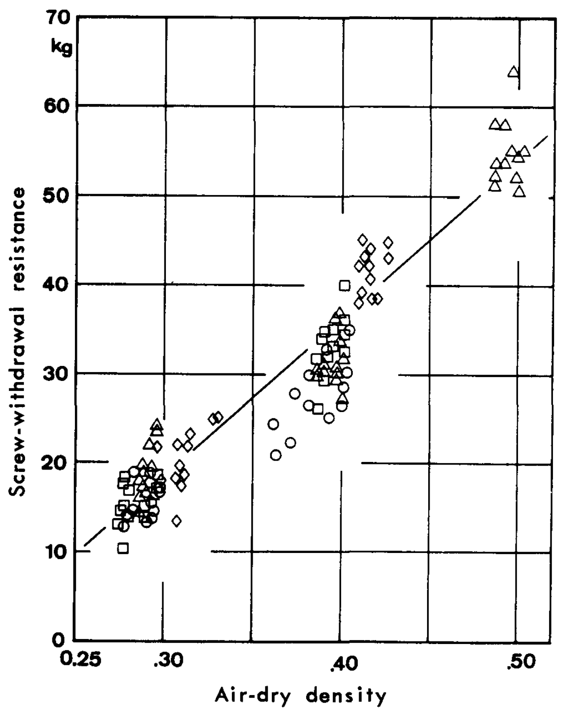

Fig. 6. Screw-withdrawal resistance as a function of the air-dry density of the particleboards

Kinds of board	From end log	From core bolts	Veneer-overlaid
Symbols	○30 △40	□30	◇30

Numbers indicate the board thickness in mm.

relation to the board density. The internal bond strength increases linearly with increasing the air-dry density of board, and does not seem to depend on any other variables taken in this experiment. The internal bond strength of the particleboards with air-dry density of 0.3 g/cm^3 is more than 2 kg/cm^2. Taking accont of the density and the compaction ratio (board density per raw material density ratio) which is calculated as about 0.75, this value is considered to be high enough.

Fig. 6 shows the screw-withdrawal resistance as a function of the air-dry density of board. It also depends only on the specific gravity of board and increases linearly with an increase of the board density.

In general, there are several factors which would cause the thickness swelling with water absorption: 1) the inherent swelling characteristic of wood particle itself, 2) the recovery of the compressive set accompanying with collapse of cells of paritcles produced in the hot-pressing, 3) the separation of the bond between particles due to the deterioration of the adhesive resin and the internal stresses caused by the swelling of particles. The first and the second factors are caused by the swelling of inner-particles and the third of inter-particles. The effect of the first factor is reversible, while that of the second and the third irreversible. In the previous paper[1], it became clear that the difference of density distribution in the thickness direction affected the ammount of thickness swelling of the board; the boards with dense face- and back-layers gave more thickness swelling than the homogeneous boards, which suggests that the recovery of the compressive set with water absorption plays an important role in the swelling of the boards. Fig. 7 shows the thickness

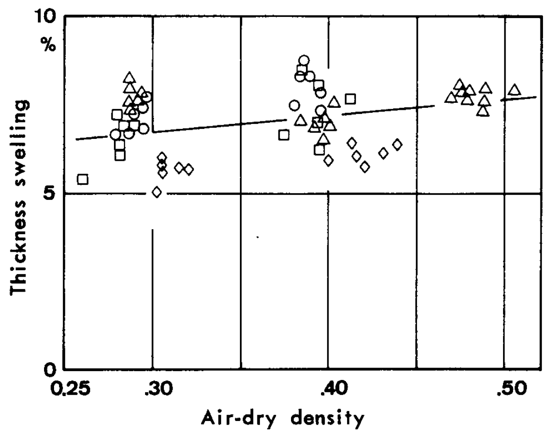

Fig. 7. Thickness swelling after 24 hrs water immersion in relation to the board density

Kinds of board	From end log	From core bolts	Veneer-overlaid
Symbols	○30 △40	□30	◇30

Numbers indicate the board thickness in mm.

swelling in relation to the board density. The thickness swelling of all the low-density particleboards showed around 7% and did not depend on the kind of raw materials and the board thickness. The veneer-overlaid boards showed a little less thickness swelling. Though the dependency of board density on the thickness swelling is not so obvious, it tends to increase with increasing board density, i.e., the compaction ratio. This also suggests the effect of the recovery of compressive set with water absorption. In fact, the thickness swelling of the particleboard with density 0.7 g/cm^3 produced in the similar condition to this experiment showed more than 10 percent[2], which supports the above tendency of increase in the thickness swelling with increasing the board density.

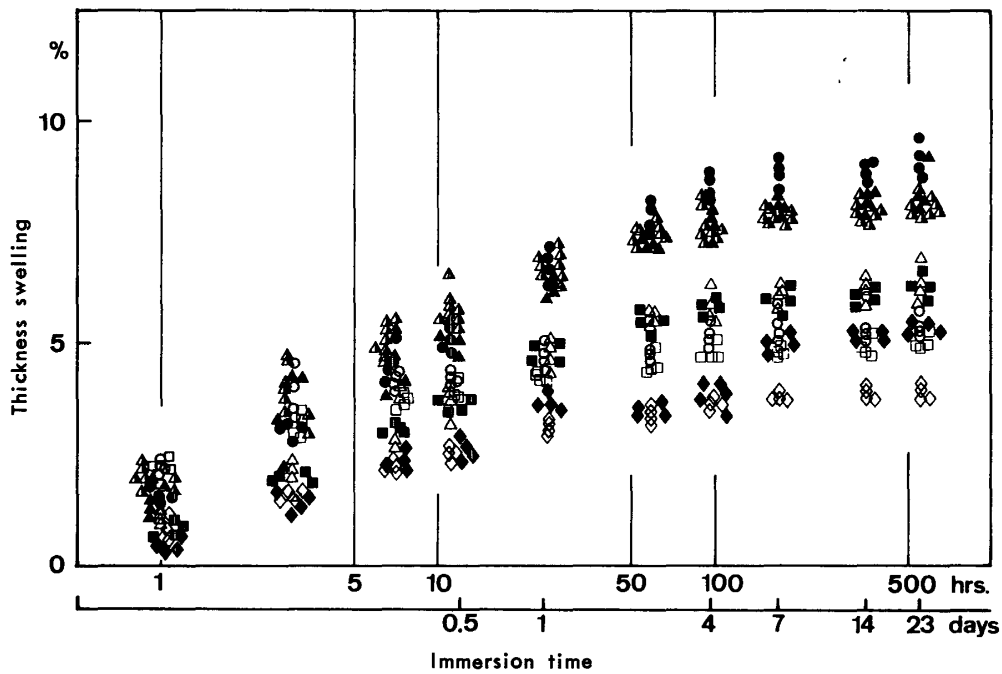

Fig. 8. Change of the thickness swelling in water immersion

Air-dry density	0.3	0.4	0.5
From end log	○30 △40	●30 ▲40	◭40
From core bolts	□30	■30	
Veneer-overlaid	◇30	◆30	

Numbers indicate the board thickness in mm.

Fig. 8 shows the change of the thickness swelling in the water immersion at 25°C. It is apparent from the figure that the thickness swelling of all the boards were less than 10 percent even in 23 days of water immersion. The thickness increases linearly with an increase of the logarithm of the immersion time from the start till 100 hours. In this period, the thickness swelling is observed to increase with an increase of absorption of water as the results of the three factors described above. However, after 100 hours, the thickness swelling increases little and seems to be saturated. It is supposed that a nominal balance is being kept at this stage between the bonding strength and the internal stresses caused by the inherent swelling of particles and by the recovery of the compressive set. This also suggests that the deterioration of the adhesive resin does not occur in the water immersion at 25°C in this period. It becomes clearer in the water immersion that the larger thickness swelling occured in the higher density particleboards, as is dicussed in the former paragragh.

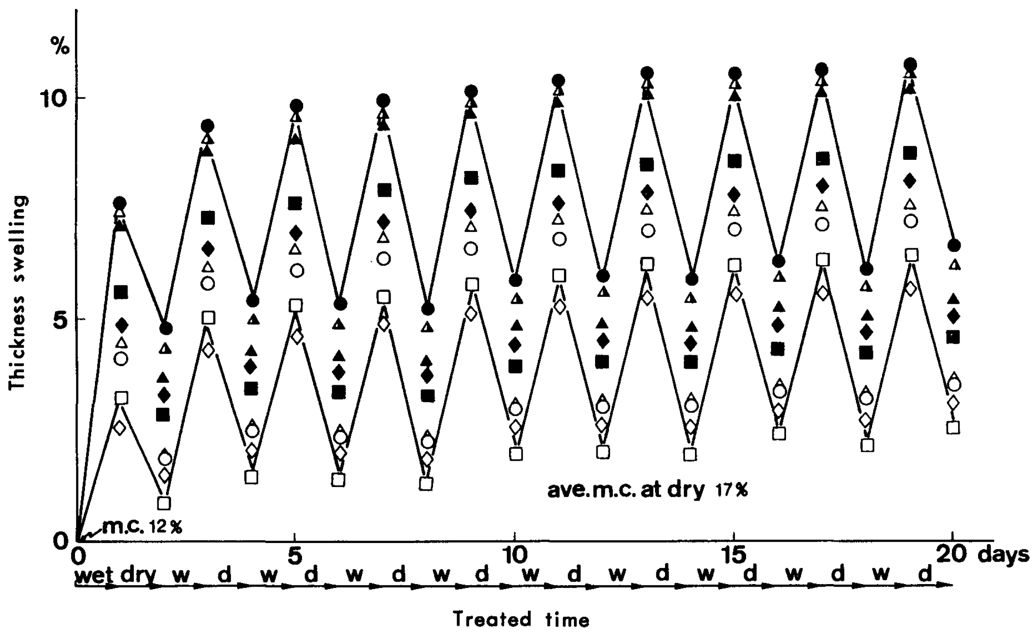

Fig. 9. Change of the thickness swelling in the dry-soak repetition

Air-dry density	0.3	0.4	0.5
From end log	○30 △40	●30 ▲40	▲40
From core bolts	□30	■30	
Veneer-overlaid	◇30	◆30	

Numbers indicate the board thickness in mm.

Fig. 9 shows the result of thickness swelling in the dry-soak repetition. The moisture content of the specimens in the wet condition was more than 100 percent, and that in the dry condition was 17% in average with relatively large deviation. The thickness change is greatly affected by the inherent shrinkage and swelling properties of wood in the moisture cotent range below the fiber saturation point. Therefore, the thickness in dry condition were corrected to that in the average moisture content. Each plot in the figure indicates the average value of 6 specimens in each condition.

It is observed in the figure that the thickness swelling in dry-soak repetition increases up to 5 cycles (10 days), then keeps a stable thickness change. The thickness swelling in the wet condition of the 10th cycle is only 5–11%, which is lower than the prescribed value of the thickness swelling after 24 hours water immersion defined by JIS. The residual swelling at dry condition can be considered to be irreversible. This irreversible swelling was calculated as 2.2, 4.5, and 5.2% for the boards with the air-dry density of 0.3, 0.4, and 0.5 g/cm^3, respectively. The result also proves that the compressive set produced in the hot-pressing has a direct effect upon the irreversible thickness swelling.

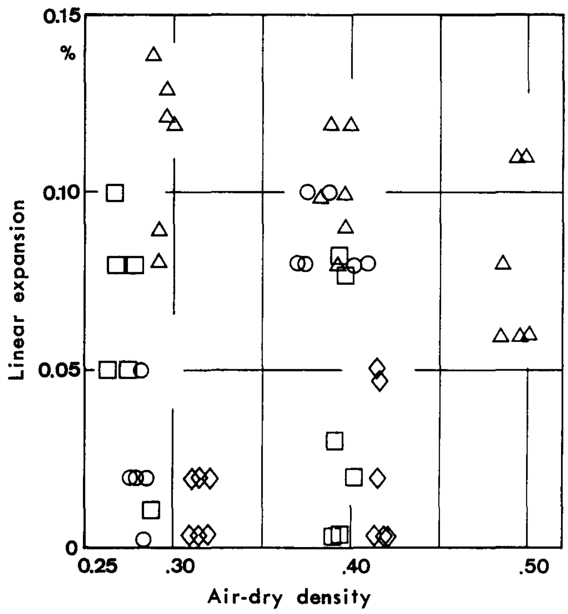

Fig. 10. Linear expansion of the low density particleboard

Kinds of board	From end log	From core bolts	Veneer-overlaid
Symbols	○30 △40	□30	◇30

Numbers indicate the board thickness in mm.

Fig. 10 shows the linear expansion of the low-density particleboards. The deviation of the observed values is rather wide and the board density dependence is not clear. The average value of linear expansion of the boards is about 0.08% and that in the face grain direction of the veneer overlaid boards is less than 0.05%. The linaer expansion of plywood perpendicular to the face grain was about 0.3% with the change of moisture content from 11% to 40%[3]. If the effect of heat due to the different treatment is neglected, the linear expansion of the low-density particleboard could be only one third that of plywoods.

5. Conclusions

Properties of low-density particleboard bonded with an isocyanate compound adhesive was examined. Bending strength in air-dry condition of the board with air-dry density 0.4 g/cm^3 is about 100 kg/cm^2, which is higher than that of Type 100 particleboard defined by JIS and the relatively high internal bond strength was obtained. Dimensional stabilities both in the plane and in the thickness directions were very high, which proves that the low-density particleboard is durable in wet condition.

When veneers were overlaid on both surfaces of the board, bending strength was much improved and the dimensional stability became even better.

Acknowledgement

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