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https://doi.org/10.5109/23830

出版情報：九州大学大学院農学研究院紀要. 30 (4), pp.275-288, 1986-09. Kyushu University
バージョン：
権利関係：

J. Fac. Agr., Kyushu Univ., 30 (4), 275-288 (1986)

Press Drying of Short Board Sawn from Young-Growth Sugi*

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(Received March 15, 1986)

For the high-moisture-content green board sawn from young-growth sugi, press-drying process was divided into three stages of first the heating, secondly the constant-rate drying and lastly the falling-rate drying, in which the change in moisture content of entire hoard could be characterized significantly by an exponential function with respect to hot pressing time, according to press-drying condition.

Under every condition ranging from 140 to 200°C and from 0.17 to 1.00 MPa, distortions of those warp-prone boards were reduced effectively without deteriorations of bending property. In particular, at 180°C and 0.50 MPa, those boards could be press dried at a high rate without both developments of undue thickness shrinkage and unacceptable drying defect.

However, alleviating the severe drying defects, which were infrequently caused irrespective of operationable condition, was demonstrated to be of importance in exploring the press-drying method available for those inferior green boards.

INTRODUCTION

Press drying, in which the material is dried by pressing between hot platens, was used on the warp-prone short board (Mataki *et al.*, 1985) sawn from young-growth sugi (*Cryptomeria japonica* D. Don) to explore the potential of this drying method in utilizing low-grade small log for products such as paneling and pallets.

The press-drying process was empirically analyzed by measuring changes in temperature, moisture content and thickness shrinkage of board during hot pressing, and then the effects of variables on the process was examined to obtain information mainly regarding drying time and thickness shrinkage.

Further investigation was relevant to the restraint of distortion, the development of drying defect, the change of internal feature and the estimation of bending property of press-dried board.

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* A part of this report was presented at the 35th Annual Meeting of the Japan Wood Research Society at Tokyo, April 1985.

EXPERIMENT

Materials

Drying material was selected from 20 logs, 2 m long, representing five separate trees of each of both 20- and 40-year-old sugi (*Cryptomeria japonica* D. Don) produced in the Kasuya Forest of Kyushu University. All logs were cut into specimen boards by sawing through and through into 20- and 25-mm-thick slubs.

By means of a planer, all specimens were surfaced to various green thickness, mainly 15 mm, plus 7.5, 10 and 20 mm, cut to a 40-cm length and an 8-cm width. Right from this preparation to press drying, these specimens were wrapped in thin polyethylen sheet.

Directly prior to press drying, these green boards had various moisture contents ranging from about 50 to about 230%, and most of them had the moisture content of over 100%. Some of them were therefore conditioned at a room temperature of 20°C and a relative humidity of 65% so as to have various moisture contents of below 100%, with the object of preparing for the experiment conducted on the effect of initial moisture content.

Press-drying apparatus and measuring procedure

The press-drying experiments were conducted in an electric heated single opening 45- by 45-cm hydraulic press, by using several platen temperatures ranging from 140 to 200°C and several specific pressures ranging from 0.17 to 1.00 MPa. Specimen boards were hot pressed until their moisture contents were reduced to 10 to 20%. In a part of experiment, the specimen boards were press dried by inserting either 20- or 40-mesh thin wire screens between their face and platen.

Both temperatures at the surface and midthickness of board during hot pressing were measured continuously by means of copper-constantan thermocouples having 0.3-mm diameter. Besides temperature, the moisture content of board during hot pressing were determined by estimating amount of water on the basis of weight of board oven-dried after press drying as follows; the change in amount of moisture of an entire board was determined a series of several removals from hot press. In order to analyze the process of press drying, each change in amount of moisture of the face and core of board during hot pressing was determined by cutting them from a series of matched boards directly after removal from hot press for various drying times over a total cycle of press drying.

Furthermore, the shrinkage in thickness of entire board was measured continuously during hot pressing by means of differential transformer with accuracy of 0.01 mm. Hereon, the contact point of its movable core rod attached to the fixed platen of the press was brought into contact with a lever support connected with the thrust platen, so that it was capable of measuring the amount of change in clearance between both platens during hot pressing of board. Thus, the thickness shrinkage of entire board could be determined throughout an overall cycle of press drying.

Determination of heat transfer coefficient

For the purpose of estimating an extent of heat transfer towards the interior of board during press drying, mean coefficient (h_m) of heat transfer from both platens to the midthickness of board throughout an overall cycle of press drying was empirically calculated by using the following equation (Byrd, 1982) ;

$$h_m = \frac{Q_{total}}{A \cdot T_a \cdot t_m} \ (\mathrm{cal/min \cdot cm^2 \cdot {}^\circ C}) \qquad \cdots\cdots (1)$$

where A: Contact area of board with both platens
T_a: Average temperature difference between platen and midthickness of board throughout overall press drying
t_m: Time required for drying to 10% m. c.
Q_{total}: Total heat quantity of $Q_s+Q_l+Q_w+Q_a$
Q_s: Sensible heat of water (1 cal/g·°C)
Q_l: Latent heat for vaporization of water (550 cal/g)
Q_w: Sensible heat of wood (0.32 cal/g·°C)
Q_a: Water absorption heat of wood (25 cal/g)

Estimation of properties of press-dried board

For boards prior to press drying and after 2 and 10 days from removal from press, the distribution of internal stress directed to width of board over its thickness was determined by measuring a series of changes in curvature of remainder of board with the aid of strain gages glued on the intact surface of board, occurring whenever slicing board little by little from one side to other side.

Distortion of board such as warp and twist after press drying was measured by means of a dial gage with accuracy of 0.01 mm. And the internal feature of board was observed at low magnifications of 100 and 200 with the aid of a scanning electron microscope, as well as the drying defect such as collapse. Furthermore, the bending property of board was tested by having a simple beam carry a center load.

Comparing with 50-°C air-dried board, these evaluations of properties of boards press-dried under various conditions were always carried out after conditioning at 20°C and 65% in relative humidity for about 2 weeks.

All experiments in this investigation were conducted with replications of either 3 or 5.

RESULTS AND DISCUSSION

Process of press drying

For the green board with high moisture content, the process of press drying could be divided fundamentally into three stages as illustrated by Fig. 1, defining the start of process to the arrival at a desired specific pressure. First in the heating period (Stage I), both temperatures of surface and interior of board underwent a rapid rise while increasing both rates of moisture reduction

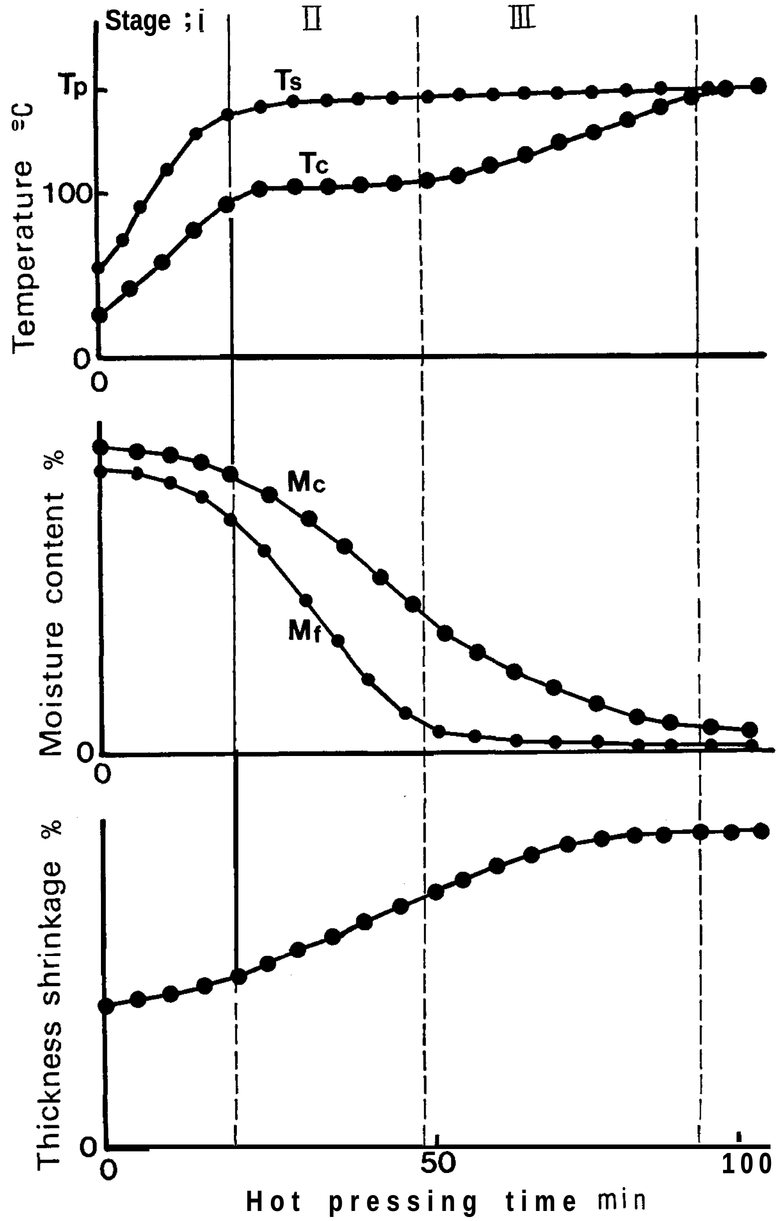


Fig. 1 Schematic of press-drying process divided into three stages. T_p: Platen temperature, T_s: Temperature at surface of board, T_c: Temperature at midthickness of board, M_f : Moisture content of face of board, and M_c: Moisture content of core of board. This process was defined to start from arrival at a desired specific pressure.

and thickness shrinkage, Secondly in the constant-rate-drying period (Stage II), the interior temperature of board remained quite stable around 100°C, while most of free water in the core of board was absorbing latent heat for evaporation as has been discussed so far (Turkia and Haygreen, 1982). And lastly in the falling-rate-drying period (Stage III), the drying region in board was gradually shifted towards the midthickness with removal of most of water from both faces, so that the interior temperature was gradually raised from about 100°C nearly to platen temperature, while both rates of moisture reduction and thickness shrinkage decreased with advancing the drying within long duration of this stage.

For each of press-drying condition in this experiment, a drying curve, representing the change in moisture content (M) in % of entire board with respect to hot pressing time (t) in min excluding press-closing time, could be expressed readily in an following exponential function (Rosen, 1978 ; FPL Press Lam Research Team, 1972) with a very high level of coefficient of correlation as illustrated by Fig. 2-l ;

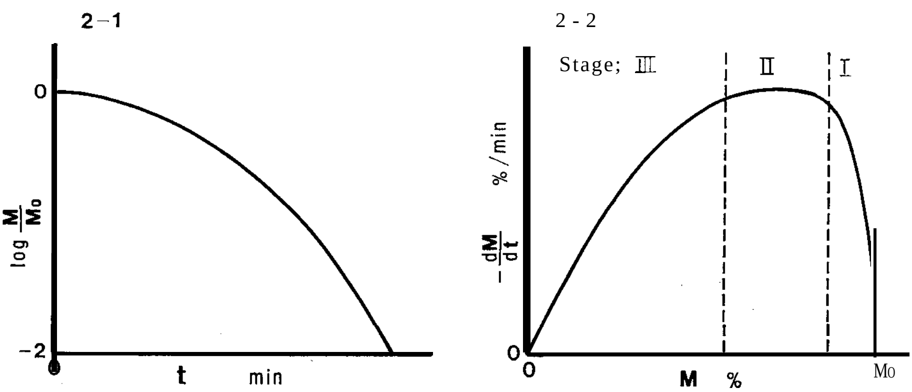


Fig. 2. Schematic of drying curve (2-l) and drying-rate curve (Z-2). M_o : Initial moisture content (%), M : Moisture content (%) of entire board during press drying, and t : Hot pressing time (min).

$$M = M_o \exp(-\alpha t^{\beta}) \qquad \cdots\cdots(2)$$

Therefore, a drying-rate curve illustrated by Fig. 2-2 was obtained from the equation (2) by differential calclus as follows;

$$-\frac{dM}{dt} = \alpha\beta t^{\beta-1} M \qquad \cdots\cdots(3)$$

Where M_o is initial moisture content of entire board in %, α is rate factor and β is reciprocal of bend factor (Rosen, 1978).

Hereon, the moisture content of entire board at the start of process could readily be substituted for the moisture content (M,) prior to press drying, because of the slight decrement to a whole amount of moisture by press closing at a desired specific pressure, and α and β were selectively derived from the method of least squares by means of a computer.

From the results of these mathematical analysis, it was noticeably reconfirmed that the press-drying process divided into three stages as described above was characterized by a drying-rate curve as illustrated by Fig. *2-2,* regarding a plateau around the peak of drying rate as the constant-rate-drying period.

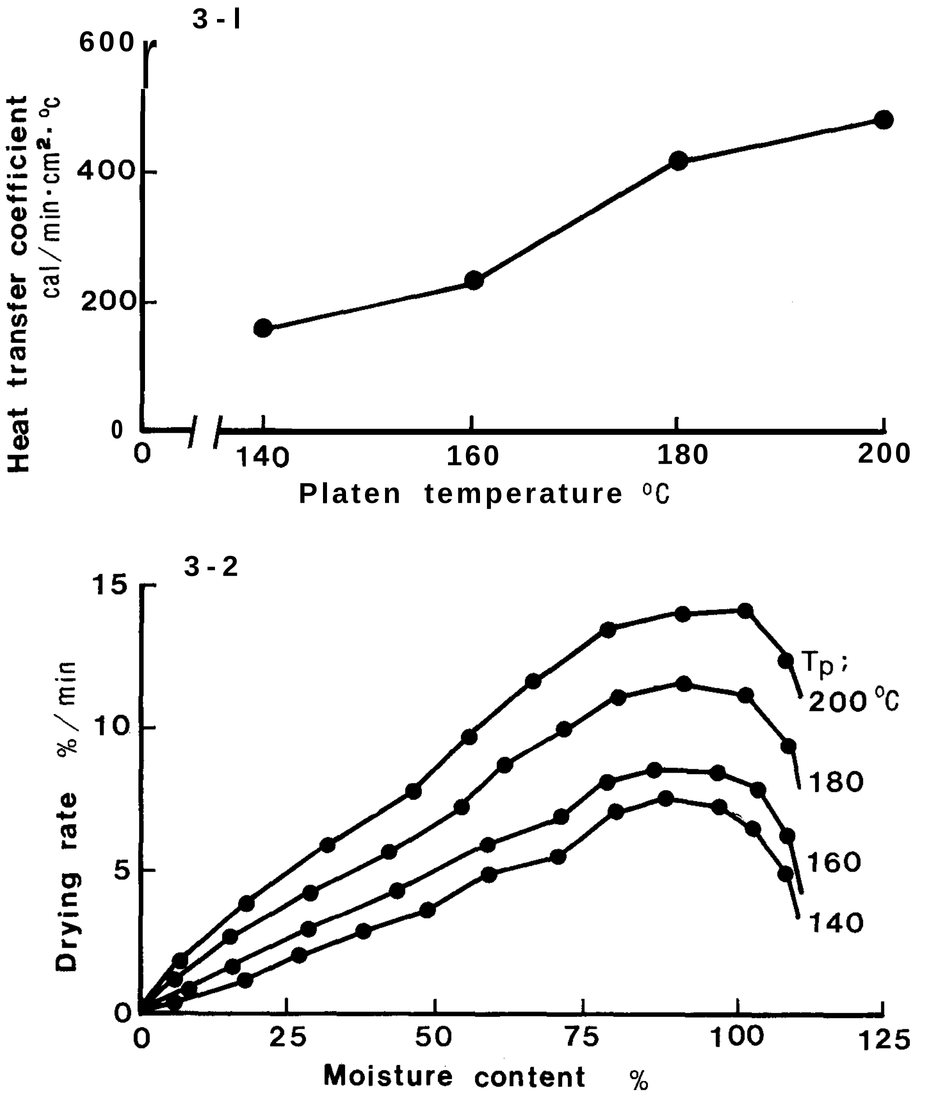


Fig. 3. Heat transfer coefficients (3-l) and drying-rate curves (3-2)at various platen temperatures at 0.5 MPa for board having thickness of 15 mm and moisture content of about 120% prior to drying.
T_p : The same symbol as shown in Fig. 1.

Effects of variables on press-drying process

With increasing in platen temperature, the heat transfer from both platens to the interior of board was so prominently intensified that the drying rate increased throughout an overall span of drying cycle as shown in Fig. 3-1. Notwithstanding the rapid increase in thickness shrinkage within the first half of press-drying cycle with increasing in platen temperature, it remained a small value at a high temperature of 180°C or over as shown in Fig. 4. This fact could presumably be traced to the early removal of moisture as a plasticizer due to the intensification of heat transfer.

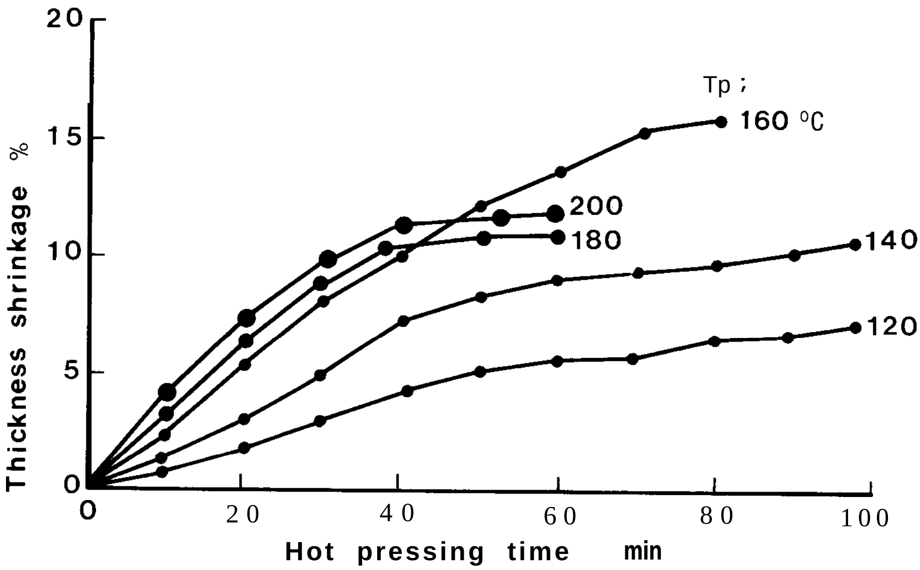


Fig. 4. Changes in thickness shrinkage during press drying at various temperatures at 0.5 MPa for board having thickness of 15 mm and moisture content of about 120% prior to drying.
T_p The same symbol as shown in Fig. 1.

Both changes in temperature and moisture content during press drying were not so dependent on specific pressure as had been observed for eastern hemlock (Ziegler and Murphy, 1971). However, the shrinkage in thickness remarkably developed at a high specific pressure of 1.0 MPa as indicated in Fig. 5. By further microscopic examination, the undue compression feature could clearly be observed in the core of board press-dried at 1.0 MPa as well as around its face, while scarcely developing in the core of board press-dried at 0.5 MPa as shown in Fig. 6.

For the board having a high intial moisture content from sap wood of young-growth sugi, heat was rapidly transferred from both platens to its interior (Fig. 7-1), so that the drying rate greatly increased within the range from the beginning to the first half of the falling-rate-drying period (Fig. 7-Z). Con-

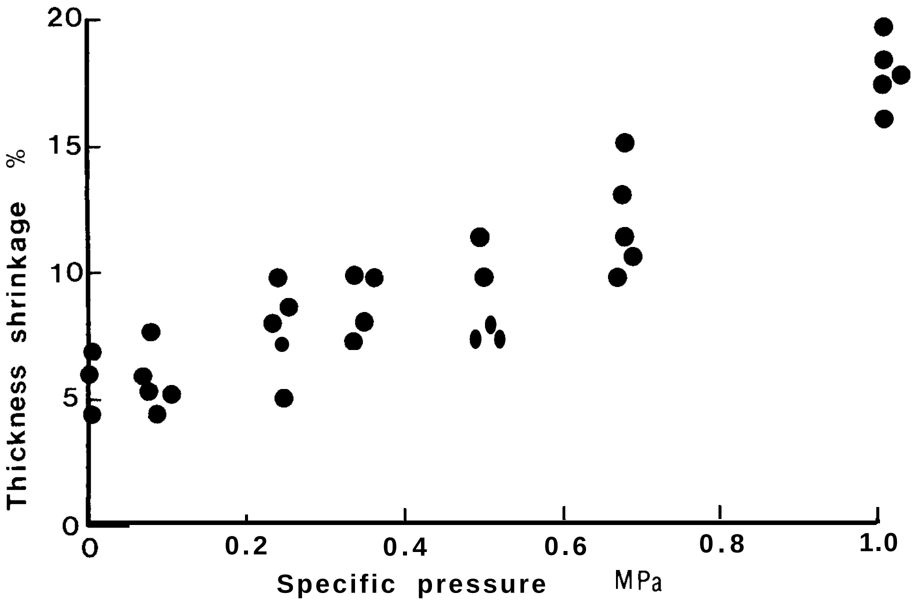


Fig. 5. Amounts of thickness shrinkage caused by press drying to 10% m. c. at several levels of specific pressure at 180°C for board having thickness of 15 mm and moisture content of about 120% prior to drying.

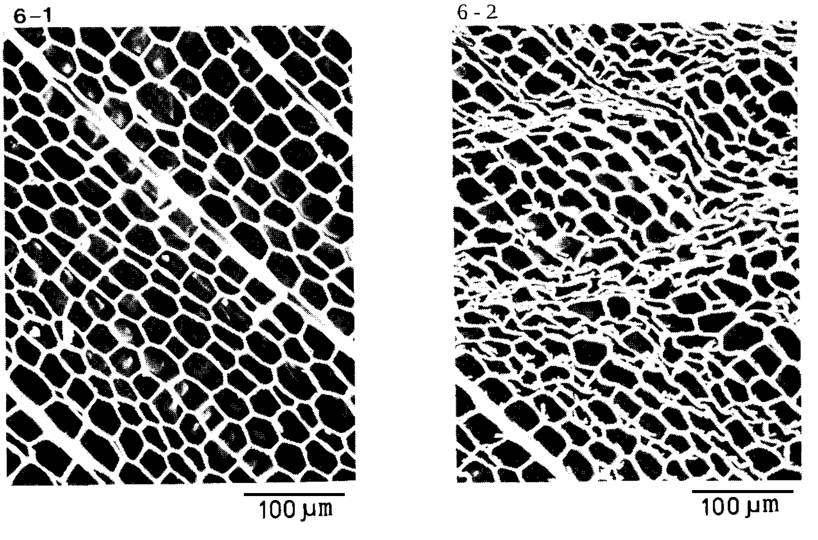


Fig. 6. Comparative internal features of both boards press-dried to 10% m. c. at 180°C at 0.5 MPa (6-l) and 1.0 MPa (6-2), which had thickness of 15 mm and moisture content of about 200% prior to drying.

sidering the noticeable relationship between the initial moisture content and the time required for drying to a desired moisture content of 10 to 20% (Fig. S-l), for the green sap-wood board with a very high moisture content of around 200%, the drying time could be estimated to approximate to that for the green heartwood board with a moisture content of about 100%. This approximation was due to the increase in drying rate during the early period as described

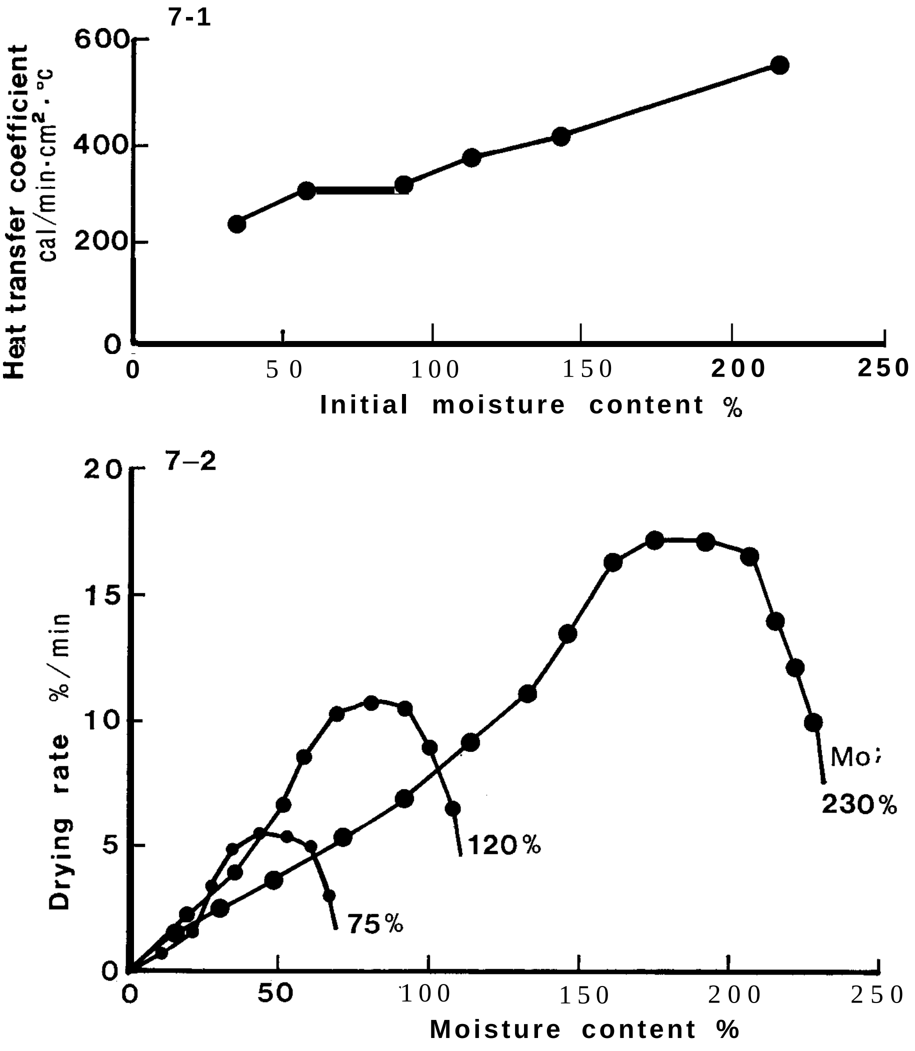
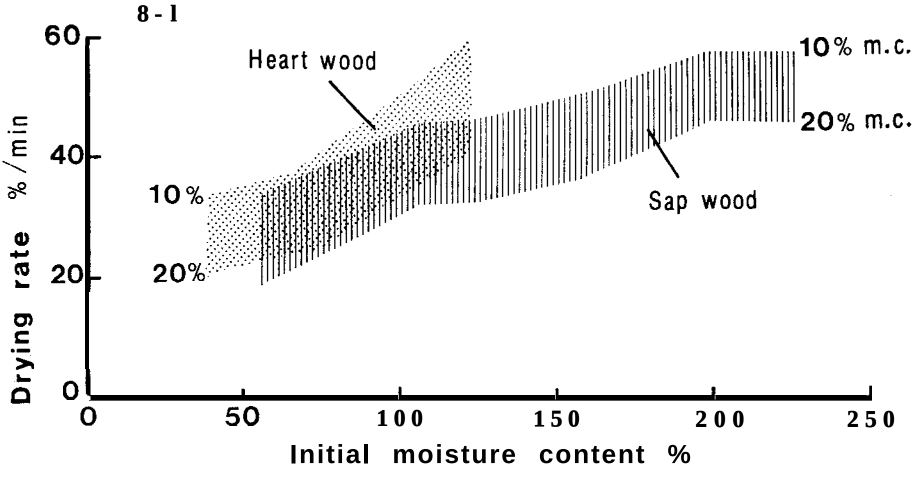


Fig. 7. Relationships of initial moisture content to coefficient of heat transfer (7-l) and drying-rate curve (7-2) in the case of press drying at 180°C and 0.5 MPa for board having thickness of 15 mm prior to drying.
M_o : The same symbol as shown in Fig. 1.

above. On the other hand, the amount of thickness shrinkage developing by press drying to the moisture content of about 10% linearly increased with increasing in initial moisture content within the range of above 50% (Fig. 8-2).

Further experiment was concerned with a few following variables relevant to the process of press drying ; the shrinkage in thickness of thin board was verified to remain such a limit as estimated for thick board, after the great



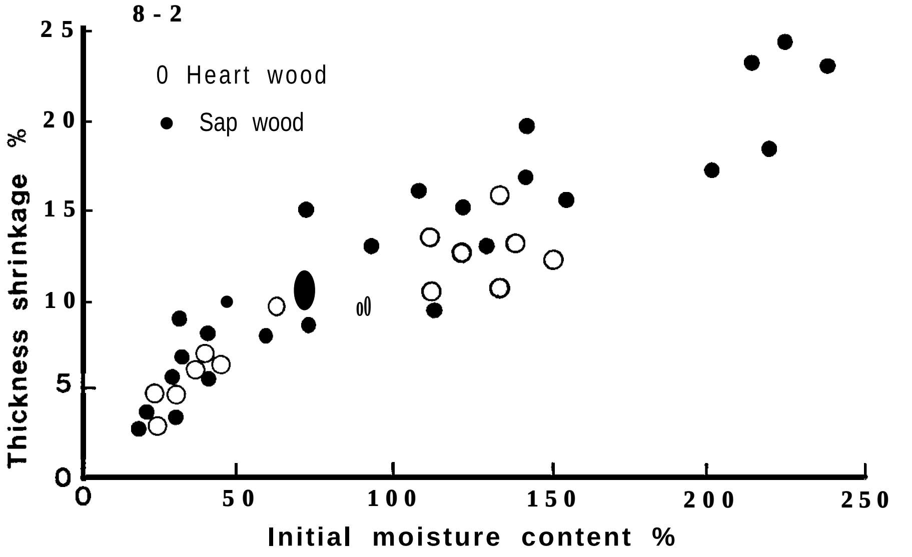


Fig. 8. Relationships of initial moisture content to time required for drying to a level of 10 to 20% m. c. (8-1) and thickness shrinkage caused by drying to 10% m. c. (8-2), in the case of press drying at 180°C and 0.5 MPa for both 15-mm-thick boards from heart-and sap-wood.

development during the early period of press-drying process. And the use of 20- or 40-mesh thin wire screen between platen and surface of board attenuated the drying rate in the overall region of press-drying process, presumably due to the depression of heat transfer from platens to the interior of board, whereas wire screen is assumed to be available for the ease with which moisture can escape from the board during hot pressing, as well as ventilated caul (Chen, 1980).

Evaluation of properties of press-dried board

After press drying, the internal stress directed to width of board was distributed throughout thickness of board. The tensile and compressive stresses were clearly exerted in the face and core respectively. And then these stresses were gradually relaxed as conditioning at a room temperature of 20°C and a relative humidity of 65% as shown in Fig. 9.

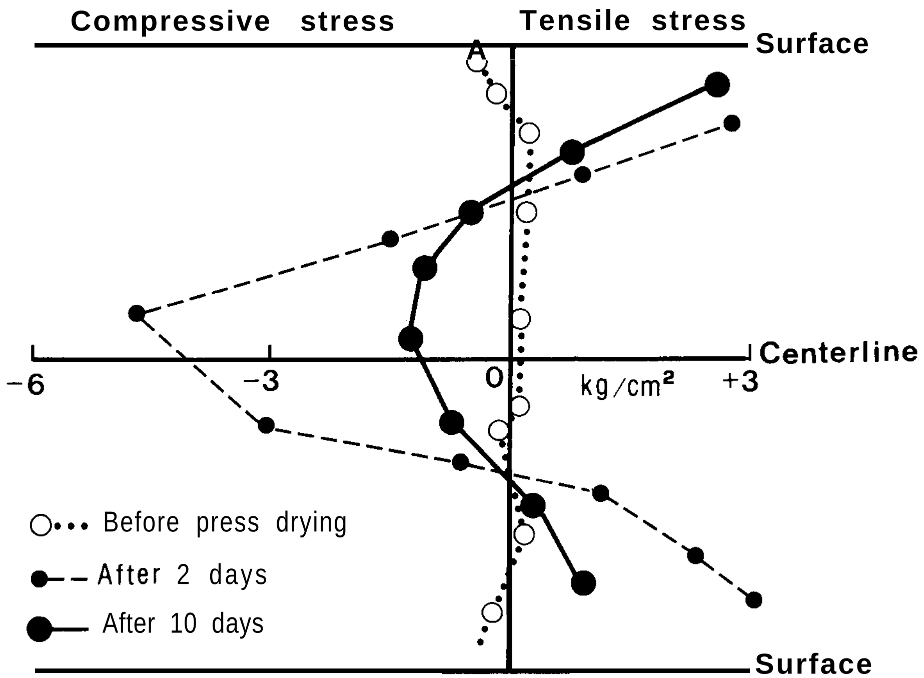


Fig. 9. Distributions of internal stress directed to width throughout thickness after 2 and 10 days of press drying to 10% m. c. at 180°C and 0.5 MPa for board having thickness of 15 mm and moistue content of about 120% prior to drying.

The press-drying method has generally been discussed to have a feasible advantage in preventing the board from distortion (Mataki *et al.*, 1985; Simpson, 1984). As demonstrated in Table 1, the press drying of warp-prone green board from young-growth sugi gave an impetus for restraining the board from various distortion such as cup, bow, crook and twist, in comparison to 50-°C air drying without restraint.

There was little difference in bending property between various press-dried

Table 1. Distortion of board press-dried under various conditions, having thickness of 15 mm and moisture content of about 120% prior to drying, in comparison with 50-°C air-dried board. Some of experiments were conducted on the difference between boards from heart and sap woods.

Condition and board			Cup	Bow	Crook	Twist
0.50 MPa	120°C		48. 1	5. 6	18. 5	3. 0
	160 °C		35.9	12. 8	13. 8	4. 6
	200 °C		37. 7	17. 2	9. 5	8.6
180 °C	20 y. o.	H. W.	49. 6	7.3	2. 8	12.
		s. W.	37.1	6. 5	2. 3	11.
0.50 MPa	40 y. 0.	H. W.	37.9	10. 5	5. 3	9.9
		s. w.	30. 1	5. 5	2.2	10. 4
180 °C	0.25 MPa		47.9	13. 9	12.6	22. 0
	0.50 MPa		31. 7	8. 3	4. 3	8.9
	0.75 MPa		28. 9	10. 4	5. 8	10.0
Air drying	50 °C		89. 0	63. 0	23. 0	92.0

y. o. : year-old
H. W. : Heart wood
S. W. : Sap wood

(x 10^{-3}m m/cm)

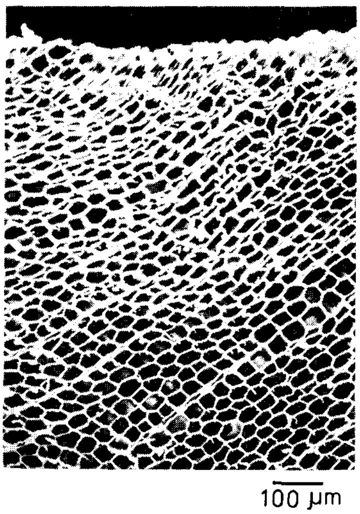


Fig. 10. An example of *severe* collapse infrequently caused by press drying to 10% m. c. at 180°C and 0.5 MPa for board having thickness of 15 mm and moisture content of about 200% prior to drying.

boards and air-dried boards as demonstrated in Table 2. An example of severe collapse occurring in the board press-dried at 180°C and 0.5 MPa (Fig. 10) was indicative of the infrequent development of drying defect caused irrespective of operationable condition of press drying.

Table 2. Bending property of board press-dried to about 10% m. c. at various platen temperatures at 0.50 MPa, having thickness of 15 mm and moisture content of about 120% prior to drying, in comparison with 50-°C air-dried board.

Condition	Board		σ_m	σ_p	E_b
140 °C	20 y. o.	H. W.	621	352	51.6
		S. W.	769	452	74.7
160 °C	20 y. o.	H. W.	493	329	52.8
		S. W.	704	276	60.4
180 °C	20 y. o.	H. W.	741	502	65.2
		S. W.	601	338	61.4
	40 y. o.	H. W.	711	370	46.6
		S. W.	838	433	80.1
200 °C	20 y. o.	H. W.	471	394	56.7
		S. W.	628	408	76.6
Air drying (50°C)	20 y. o.	H. W.	769	373	43.1
		S. W.	815	551	68.3
	40 y. o.	H. W.	540	310	35.7
		S. W.	820	459	51.7

y. o., H. W. and S. W. : The same symbols as shown in Table 1.
σ_m : Bending strength (kgf/cm^2)
σ_p : Bending stress at proportional limit (kgf/cm^2)
E_b : Young's modulus in bending ($\times 10^3 kgf/cm^2$)

CONCLUSION

Green boards sawn out of young-growth sugi were press dried to a desired level of moisture content of 10 to 20% under various conditions ranging from 140 to 200°C and from 0.17 to 1 .OO MPa, while passing through three stages of first the heating, secondly the constant-rate drying and lastly the falling-rate drying. For each of those press-drying conditions a drying curve could be characterized by an exponential function with a very high level of coefficient of correlation.

At 180°C or over at 0.5 MPa the boards with very high moisture content of around 200% could be press dried without an exaggerated prolongation of drying time, due to the high-rate removal of moisture within the range from the beginning to the first half of falling-rate-drying period. Besides, the thickness shrinkage was limited to a low level, resulting from the rapid removal of moisture as a plasticizer for a short drying time due to activation of heat transfer.

By using platen temperature of 180°C, the undue compression feature scarcely occurred at 0.5 MPa or below whereas developing at 1.0 MPa. Furthermore, after press drying under various above-described conditions, the distortion of board was reduced to a very large extent without deteriorating bending property, and the severe drying defects were, however, infrequently caused irrespective of operationable condition. Alleviating the drying defects was, therefore, assumed to be indispensable for press drying method available for the inferior warp-prone board sawn out of young-growth sugi.

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