Effect of Hole Diameter and Drying Condition on Shrinkage and Defect of Sugi (*Cryptomeria japonica* D. Don) Wood in Convective Air Dryer

Yustinus Suranto and Kazuo Hayashi

Abstract

Sugi wood containing pith in the centre of specimen has a very low drying ability and very easy to suffer a defect due to drying on convective dryer. Trunk of sugi trees grown artificially in Matsuyama forest district were cut longitudinally to some rectangular samples in dimension of 12.3 cm x 12.3 cm x 1.5 cm (length). Every six of samples were grouped in one group. The first unit of the sample in every group was intended to measure initial moisture content and another five units of the samples were subjected to treatment in a hole in the center of the sample with a diameter's dimension of 0 cm, 2.46 cm, 3.075 cm, 4.1 cm and 6.15 cm respectively. The first until the ninth group were dried in air convective dryer with temperature of 50°C and relative humidity of 80%, while the tenth until the nineteenth group were dried at temperature of 80°C and relative humidity of 87%. Every stage of drying, each of the samples was weighted and measured for tangential and radial shrinkage as well as length of crack. Data was analyzed using completely randomized design in a factorial arrangement.

The result showed that the smaller hole diameter and the higher drying condition, the lower final moisture content, the higher tangential shrinkage, the higher radial shrinkage and the longer of the total crack.

Keywords: wood, drying condition, hole's diameter, shrinkage, defect.

Introduction

Sugi trees (*Cryptomeria japonica* D.Don) is a dominant tree growing in forest area of Japan. This condition makes sugi wood is choosen as a main raw material to fulfill the need of wood industries, including wood construction and wood furniture industries in Japan. However, sugi wood also has some weaknesses, such as very high moisture content at green condition, very low of dry ability, and very easy to get drying defects (Hayashi *et al*. 1992)

To eliminate these weaknesses, some treatments had already been developed. Some of these treatments are as follows: insition on the surface of wood, steaming to wood, pressing and compacting of the wood, making a gap as long as the length dimension of the wood, and local explosion by pre-steaming. Result of these treatments had not yet satisfied in eliminating these weaknesses (Hayashi 1999). This background inspired the writers to conduct this research. The treatments employed different diameters of hole dimension. Treatment in a variable in diameter of hole's dimension can be expected as a way to eliminate the weaknesses of sugi wood in drying process.

Wood drying process is a process to evaporate moisture out from the wood. In this process, free moisture and bound moisture are evaporated to the surrounding air. Process of drying requires driving force, namely moisture gradient between moisture in the wood and moisture in the surrounding air. Wood moisture must be higher compared to air moisture. The higher moisture gradient, the faster the drying process. (Haygreen and Bowyer 1982)

Process of moisture evaporation is begun on the outer part of the wood, successively followed by the inner part of the wood. Rate of moisture movement from inner part to the outer part of the wood depends on relative humidity of the surrounding air, the steepness of the moisture gradient, and the temperature of the wood. The lower the relative humidity, the greater the capillary flow. In connection to the temperature, the higher the temperature of the wood, the faster the rate at which the moisture moves from the wetter interior to the drier surfaces. If the temperature is too high, wood defects in the form of deformation, collapse, and cracks (Rasmussen 1961).

Materials and Methods

This experiment was done in the laboratory of wood science and technology at Ehime University. This research used three stems of thirty years old of sugi wood grown artificially at community forest district at Matsuyama prefecture, Japan. Each stem is in normal condition, healthy and as much as possible free of defect, include knot. Each stem was cut with double blades bend saw to rectangular shape in dimension of 12.3 cm x 12.3 cm. This rectangular shape of lumber was then cut again longitudinally with circular saw .to obtain some samples in length dimension of 1.5 cm. Every six unit of the samples was grouped in a group. The first unit of sample in every group was intended to measure initial moisture content, and the other five units of the samples were subjected to a treat with a circular hole in the centre of the sample with a diameter's dimension of 0 cm, 2.46 cm, 3.075 cm, 4.1 cm and 6.15 cm respectively.

Samples intended for measuring initial moisture content were weighted and then dried in an electric oven. Drying process was held continuously until the samples were free from moisture which was marked by the constant weight of the sample.

The first until the ninth of the group were dried in low condition drying with temperature of 50°C and relative humidity of 80%, while the tenth until nineteenth group were dried in medium condition drying with temperature of 80°C and relative humidity of 87%. Before drying process and every six hours duration of drying, each of the samples was weighted and was measured the tangential and radial dimension, as well as the existance of crack and it's development.

Results and Discussion

Results on each character of sugi wood drying, namely final moisture content, final tangential shrinkage, final radial shrinkage, final tangential and radial shrinkage ratio and total length crack at the end of drying are presented in Tables 1, 2, 3, 4 and 5 respectively.

Each of those data was analyzed with analysis of variance in order to know the effect of hole's diameter and drying condition and interaction of these two factors. Result of this analysis is presented in Tables 6, 7, 8, 9 and 10 for final moisture content, final tangential shrinkage, final radial shrinkage, final tangential and radial shrinkage ratio and total length crack at the end of drying, respectively.

Table 1. Final Moisture Content (%).

Drying condition	Hole diameter dimension compared to sample width dimension 0	1/5	1/4	1/3	1/2	Mean
50°C, 80%	14.44	14.83	14.91	15.82	15.73	15.15
80°C, 87%	11.84	12.05	12.87	14.22	14.33	13.07
Mean	13.23	13.54	13.96	15.08	15.09	14.11

Table 2. Tangential Shrinkage (%).

Drying condition	Hole diameter dimension compared to sample width dimension 0	1/5	1/4	1/3	1/2	Mean
50°C, 80%	1.687	1.687	1.824	1.902	2.128	1.851
80°C, 87%	2.152	2.144	2.214	2.367	2.470	2.269
Mean	1.904	1.900	2.016	2.123	2.288	2.060

Table 3. Radial Shrinkage (%).

Drying condition	Hole diameter dimension compared to sample dimension 0	1/5	1/4	1/3	1/2	Mean
50°C, 80%	1.638	1.767	1.993	2.080	2.336	1.963
80°C, 87%	2.150	2.218	2.258	2.448	2.751	2.365
Mean	1.877	1.978	2.117	2.252	2.530	2.164

Table 4. Tangential and Radial Shrinkage Ratio (%).

Drying condition	Hole diameter dimension compared to sample width dimension 0	1/5	1/4	1/3	1/2	Mean
50°C, 80%	1.029	0.956	0.924	0.917	0.912	0.948
80°C, 87%	1.005	0.968	0.984	0.976	0.924	0.965
Mean	1.018	0.961	0.952	0.940	0.908	0.956

Table 5. Total Length Crack at the End of Drying (cm).

Drying condition	Hole diameter dimension compared to sample dimension 0	1/5	1/4	1/3	1/2	Mean
50°C, 80%	4.177	2.193	0.527	0	0	1.380
80°C, 87%	3.589	3.067	2.602	1.275	0.221	2.151
Mean	3.903	2.601	1.496	0.595	0.103	1.765

Table 6. Analyses of Variance of Final Moisture Content.

Source of variation	Degree of Freedom	Sum of Square	Mean Square	Computed F	Probability
Treatment	9	131.025	14.558	9.93 **	0.0001
Drying condition	1	80.142	80.142	54.64 **	0.0001
Hole's diameter	4	45.226	11.306	7.71 **	0.0001
Interaction	4	5.657	1.414	0.96 *	0.4332
Error	65	95.338	1.466		
Total	74	226.364			

Note: ** is significant at 1% level, * is significant at 5% level, NS is not significant.

Table 7. Analyses of Variance of Final Tangential Shrinkage.

Source of variation	Degree of Freedom	Sum of Square	Mean Square	Computed F	Probability
Treatment	9	4.919	0.546	22.71 **	0.0001
Drying condition	1	3.272	3.272	135.97 **	0.0001
Hole's diameter	4	1.596	0.399	16.58 **	0.0001
Interaction	4	0.500	0.012	0.52 NS	0.7215
Error	65	1.564	0.024		
Total	74	6.483			

Note: ** is significant at 1% level, * is significant at 5% level, NS is not significant.

Table 8. Analyses of Variance of Final Radial Shrinkage

Source of variation	Degree of Freedom	Sum of Square	Mean Square	Computed F	Probability
Treatment	9	7.044	0.782	21.93 **	0.0001
Drying condition	1	3.019	3.019	84.59 **	0.0001
Hole's diameter	4	3.896	0.974	27.29 **	0.0001
Interaction	4	0.128	0.032	0.90 *	0.4688
Error	65	2.320	0.035		
Total	74	9.365			

Note: ** is significant at 1% level, * is significant at 5% level, NS is not significant.

Table 9. Analyses of Variance of Tangential and Radial Shrinkage Ratio.

Source of variation	Degree of Freedom	Sum of Square	Mean Square	Computed F	Probability
Treatment	9	0.123	0.013	5.92 **	0.0001
Drying condition	1	0.005	0.005	2.54 NS	0.1159
Hole's diameter	4	0.097	0.024	10.49 **	0.0001
Interaction	4	0.020	0.005	2.20 NS	0.0788
Error	65	0.150	0.002		
Total	74	0.273			

Note: ** is significant at 1% level, * is significant at 5% level, NS is not significant.

Table 10. Analyses of Variance of Total Length Crack at the End of Drying.

Source of variation		Sum of Square	Mean Square	Computed F	Probability
Treatment	9	168.502	18.722	12.62 **	0.0001
Drying condition	1	11.102	11.102	7.48 **	0.008
Hole's diameter	4	142.036	35.509	23.93 **	0.0001
Interaction	4	15.353	3.840	2.59 *	0.044
Error	65	96.456	1.483		
Total	74	264.959			

From analyses of variances, it is seen that the treatments had very significant effects on all research parameters. Drying condition influenced very significantly on final the moisture content, final tangential shrinkage, final radial shrinkage, and total length crack at the end of drying, but did not influence significantly the final tangential and radial shrinkage ratio. Hole's diameter also influenced very significantly on all research parameters, namely for final moisture content, final tangential shrinkage, final radial shrinkage, as well as final tangential and radial shrinkage ratio, and length crack at the end of drying. Interaction of drying condition and hole's diameter influenced to the final moisture content, final radial shrinkage, and total length crack at the end of drying but did not influence final tangential shrinkage, final tangential and radial shrinkage ratio.

Moisture content of dried wood (15.15%) resulted by medium drying condition (80°C and 87%) was lower than moisture content of dried wood (13.07%) resulted by low drying condition (50°C and 80%). On the contrary, final tangential shrinkage, final radial shrinkage, final tangential and radial shrinkage ratio as well as total length crack of the wood resulted by medium drying condition (80°C and 87%) were higher than those resulted by low drying condition (50°C and 80%). Final tangential shrinkage were 1.851% and 2.269%, final radial shrinkage were 1.963% and 2.365%, final tangential and radial shrinkage ratio were 0.948% and 0.965% as well as total length crack were 1.380 cm and 2.151 cm respectively for the dried wood resulted by low drying condition (50°C and 80%) and the dried resulted by medium drying condition (80°C and 87%).

These results are a normal tendency, because the higher drying condition, the lower the final moisture content, but accompanied by higher tangential shrinkage, higher radial shrinkage and longer of the total crack. These tendencies are in line with the theory of wood drying proposed by Rasmussen (1961). Rasmussen stated that the higher dry bulb temperature and higher relative humidity in the process of drying, will be the lower the final moisture content, but higher tangential shrinkage, higher radial shrinkage and longer of the total crack of dried wood.

The above explanations are about the effect of drying condition on characters of wood drying. Now, the effect of treatment in the form of dimension of hole's diameter on the central of the wood sample to characters of wood will be elaborated in the proceeding discussion.

Moisture contents of dried woods were 13.23%, 13.54%, 13.96%, 15.08% and 15.09% for sample with diameter of hole of 0 cm, 2.46 cm, 3.075 cm, 4.1 cm and 6.15 cm, respectively. It is seen that the higher dimension of hole's diameter, the higher moisture content of the dried wood. These tendencies also occurrs for final tangential shrinkage, and final radial shrinkage. This means that the higher dimension of hole's diameter, the higher final tangential shrinkage, and the higher final radial shrinkage. Based on the data presented in Table 2, the final tangential shrinkages were 1.904%, 1.900%, 2.016%, 2.123%, and 2.288% for sample with diameter of hole of 0 cm, 2.46 cm, 3.075 cm, 4.1 cm and 6.15 cm, respectively. Mean while, based on the data presented inTable 3, the final tangential shrinkages were 1.877%, 1.978%, 2.117%, 2.252%, 2.530% for sample with diameter of hole of 0 cm, 2.46 cm, 3.075 cm, 4.1 cm and 6.15 cm, respectively.

The tendency of the higher value in line with the higher dimension of hole's diameter for the three parameters, namely moisture content of dried wood, final tangential shrinkage, and final radial shrinkage, may be caused by variability of specific gravity of wood. Based on the theory of variability of specific gravity on radial directions of conifer wood, specific gravity value increases from the pith to the bark (Soenardi 1976). Increasing specific gravity causes increasing wood substance. Increasing of wood substance will also increase capacity to absorb water and increasing also shrinkage's degree.

In case of final tangential and radial shrinkage ratio as well as total length crack at the end of drying, the contrary phenomena were occurred. This means that higher dimension of hole's diameter, the lower final tangential and radial shrinkage ratio as well as the lower total length crack at the end of drying. Based on the data presented inTable 4, final tangential and radial shrinkage ratio were 1.018, 0.961, 0.952, 0.940, 0.908 for sample with diameter of hole of 0 cm, 2.46 cm, 3.075 cm, 4.1 cm and 6.15 cm, respectively. Mean while, based on the data presented in Table 5, total length crack of the sample are 3.903 cm, 2.601 cm, 1.496 cm, 0.595 cm, 0.103 cm for sample with diameter of hole of 0 cm, 2.46 cm, 3.075 cm, 4.1 cm and 6.15 cm respectively.

The above facts may be caused by the existence of the hole in the centre of the wood. Existence of the hole in the centre of wood made a certain space in the wood which could receive movement of radial shrinkage fully. Mean while, movement of tangential shrinkage can not express freely. That is why, the bigger hole, the bigger radial shrinkage but the tangential shrinkage was relatively constant.

Conclusions

Hole made in the centre of sugi wood influence the values of moisture content, tangential shrinkage, radial shrinkage, tangential shrinkage and radial shrinkage ratio, and intensity of crack defect of dried wood. The bigger dimension of hole's diameter, the bigger moisture content of dried wood, the bigger final tangential shrinkage, and the bigger final radial shrinkage but accompanied by the lower final tangential and radial shrinkage ratio as well as the lower total defect of wood at the end of drying. Optimum size of hole was obtained on diameter of 1/3 of sample width dimension. These samples has a moisture content of 15.08%, tangential-radial shrinkage ratio of 0.94, and the total crack length of 0.595 cm.

Drying condition influence the values of moisture content, tangential shrinkage, radial shrinkage, tangential shrinkage and radial shrinkage ratio, and intensity of defect of dried sugi wood. The higher drying condition, the lower moisture content, but the higher final tangential shrinkage, the higher final radial shrinkage, the higher final tangential and radial shrinkage ratio as well as the higher total defect of the dried wood. Optimum drying condition was obtained on temperature of 50°C and relative humidity of 80%. These drying conditions produce dried wood with a moisture content of 15.15%, tangential-radial shrinkage ratio of 0.948, and the total crack length of 1.380 cm.

References

Hayashi, K.; T. Kanagawa, M. Yasuzima. 1992. Improvement of Drybility by Local Steam Explotion for Japanese Cedar. Proceeding of Third IUFRO Conference: Understanding the Wood Drying Process, A Synthesis of Theory and Practices. Vanek M (Editor). Vienna. Austria.

Hayashi, K. 1999. Pretreating to Increase Drybility of Wood in Process of Drying. General Lecture on Faculty of Forestry, Gadjah Mada Univerisity. Yogyakarta.

Haygreen J.G; J.L. Bowyer, 1982. Forest Product and Wood Science, The IOWA State University Press. AMES.

Rasmussen, E.F. 1961. Dry Kiln. Operators Manual. USDA. Washington.

Soenardi, 1976. Wood Structure and Properties (Indonesian language). Foundation Supported for Faculty of Forestry, Gadjah Mada University. Yogyakarta

Yustinus Suranto
Faculty of Forestry, Gadjah Mada University
Kampus Bulaksumur, Yogyakarta 55281, Indonesia
Tel : 62 274-512102
Fax : 0274-550541
E-mail : surantoyustinus@yahoo.com

Kazuo Hayashi
Faculty of Agriculture, Ehime University,
Matsuyama, Japan
Tel : 81 89 927-9021
Fax : 81 89 927-8820,
E-mail : hayashi.kazuo.my@ehime-u.c.jp