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Development of Hybrid Kiln Drying System with Radio Frequency Heating for the Sugi Boxed Heart Timber

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In this study, proper applied stage of the radio–frequency (RF) heating during kiln drying based on the quality concerning the surface checks of the boxed heart timbers was examined.

At the stage of the RF heating the moisture contents decreased clearly at the internal parts of timbers. The surface stress of the sugi (*Cryptomeria japonica* D. Don) boxed heart timber changed into the compression stress by the RF heating in any drying stage. The surface checks increased according to the decrease of the moisture content. However, the increase of the area and the width of the surface checks in the Link 3 were comparatively low, and the quality of these boxed heart timbers seemed relatively good. The amount of electric energy of RF heating in the Link 3 was fewer than that in the Link 1, 2.

INTRODUCTION

The adequate drying of sugi boxed heart timbers for the structural members with large dimension requires a long time in general because the moisture content (MC) at the inner part does not decrease easily.

Fang *et al.* (2001) reported radio–frequency/vacuum (RF/V) drying method could dry 165–240 mm diameter roundwoods from their sapwood MC of over 80% to a final MC of less than 25%, in less than 16 hours. Furthermore, RF/V drying produced poles with a uniform final MC.

Moisture flow characteristics of thick hemlock lumber during RF/V drying were examined (Zhang *et al.*, 1997). The results showed that short specimens dried faster than long ones at MCs above the fiber saturation point.

Avramidis *et al.* (1994) had reported that thick western redcedar can be dried by RF/V without degrade. Furthermore, it was established that very high temperature and significant pressure gradients would develop in the longitudinal direction of the boards. And both gradients were affected by the electrode voltage and significantly contributed to the high drying rates achieved with this method.

As mentioned above, the effectiveness of the RF heating and vacuum drying in the improvement of a drying speed had been shown.

Recently, the hybrid drying system of RF heating and conventional kiln air heating has been commercialized in Japan for these heavy timbers. Even the inner layer can be dried adequately in a short term by this system. Especially, large tension set on the surface layer of the boxed heart timber can be formed with high

temperature and low humidity condition at the initial stage of drying, and the surface checks are suppressed (Yoshida *et al.*, 2000).

However, it is necessary to develop the application system of RF heating. In this study, proper applied stage of the RF heating was examined based on the quality concerning the surface checks, which is the most important defect in the quality of the dried timber.

MATERIALS AND METHODS

Materials

Drying test was carried out on 9 sugi boxed heart square timbers of 120 mm × 120 mm × 500 mm (Longitudinal direction). Before test, 20 mm thick cross sections at the points of 50 mm from the ends of timbers were sampled, and initial MC distributions in the cross section were measured by oven dried method. The rest 430 mm specimens were used for the drying test after coating the both ends by silicon. Three specimens were dried in each system method.

Drying methods

Three drying systems, which are conventional kiln drying of D. B. T. 80°C and W. B. T. 75°C linking with RF heating in periods to 30% MC (Link 1), 30% MC to 20% MC (Link 2) and 20% MC to 15% MC (Link 3), were pursued in this research (Table 1).

Figure 1 shows the arrangement method of the specimens during RF heating. These specimens were placed between a charged and a grounded electrode under atmospheric pressure. For measuring the tem-

Table 1. Hybrid kiln drying methods of Link 1, 2 and 3

Moisture content	Green ~ 30%	30% ~ 20%	20% ~ 15%
Link 1	RF heating	Kiln drying	
Link 2	Kiln drying	RF heating	Kiln drying
Link 3	Kiln drying		RF heating

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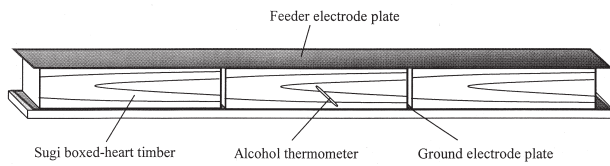


Fig. 1. Arrangement of the specimens in RF heating.

perature of the specimen during RF heating, center specimen of three timbers was drilled a hole, and put an alcohol thermometer and sealed with epoxy resin. The temperature of the specimen was controlled at 102°C by on-off automatic operation of the RF.

The RF heating was operated only daytime, and this stage took three days for any drying system (Link 1, 2 and 3). The changes of the specimen temperature during the RF heating in daytime are shown in Fig. 2. In any drying system, the rising speed of the specimen temperature by the RF heating is fast in the first day, and slow in the third day. It is supposed that the

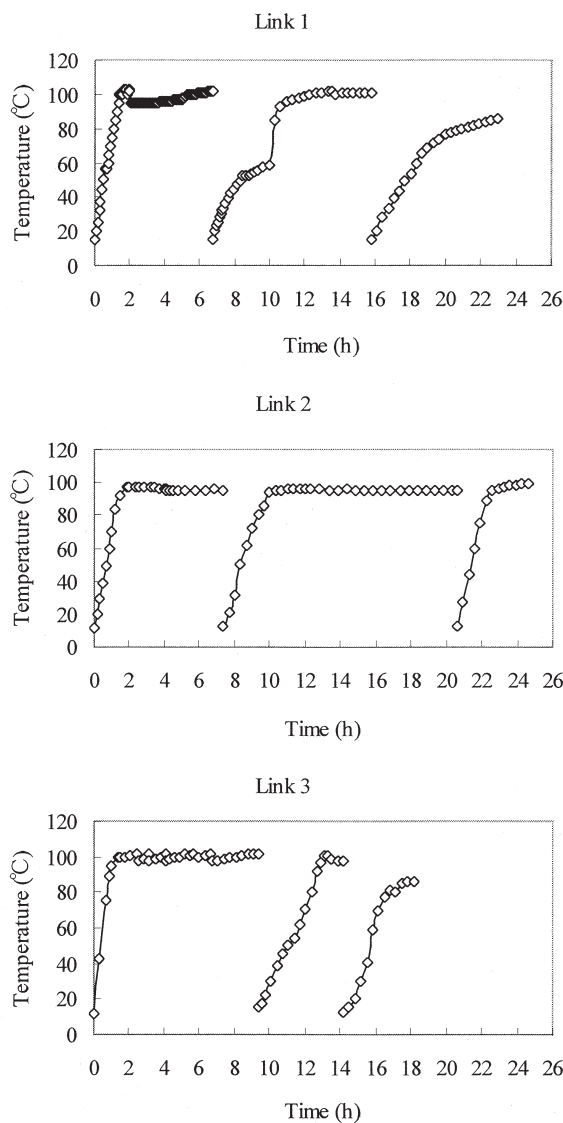


Fig. 2. Temperature changes of the timbers during RF heating.

existence of water with a high dielectric has an influence on the energy conversion efficiency.

Measurements

MC distributions of the cross section (oven dry method, divided 36 pieces in the cross section), surface checks and released strains in the direction of the width were measured at each drying stage.

RESULTS AND DISCUSSION

Drying curve

Figure 3 shows dry curves in the Link 1, 2 and 3. In every drying test, a rapid decrease of MC was found in the stage of the RF heating. The decrease of MC at the early stage RF heating is larger than that at the latter stage RF heating. However, there was no large difference of the overall drying time in the Link 1, 2 and 3.

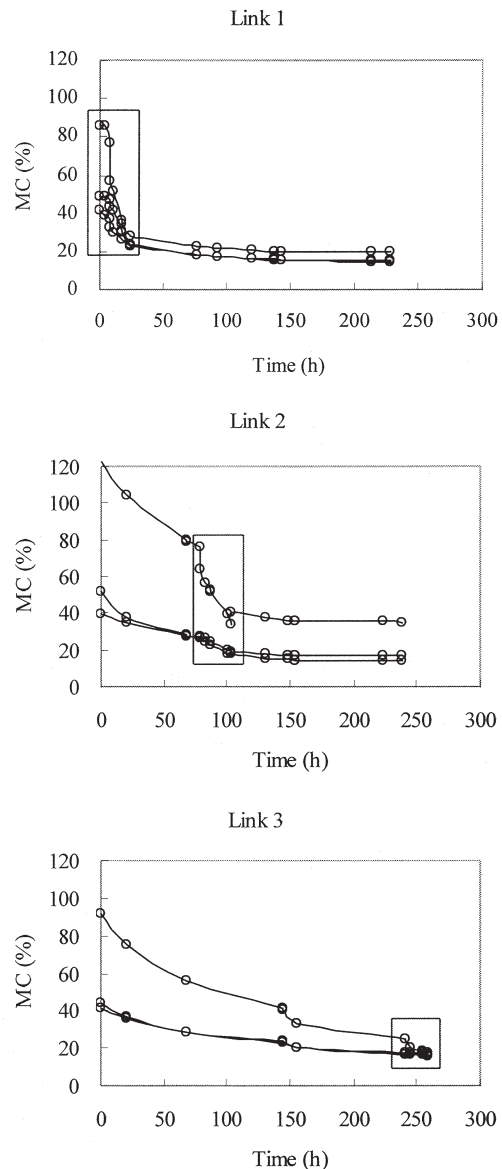


Fig. 3. Drying curve of hybrid kiln drying systems with RF heating stage.

Note: Square mark: RF heating stage.

MC distribution

MC distributions in the cross section during drying on the Link 1, 2 and 3 are shown in Fig. 4. MCs of the outer layers decreased greatly during drying with air heating. On the other hand, MCs decreased clearly at the internal layers of timbers at the stage of the RF heating. Especially, MCs of the internal parts have lowered more than those in the outer parts in the Link 1 and 2. The surface stress in Link 3 has also changed into the compression stress after the third stage with the RF heating, even though MCs in the outer part were lower than the inner part. This reason might be a large drying set in tension on the surface layer of the boxed heart timber, which was dried with air heating in the first and the second stage.

Surface stress

Figure 5 shows the surface released strains of sugi

boxed heart timbers during drying on the Link 1, 2 and 3. After the first stage of drying with RF heating in the Link 1, the surface stress was compression. But the stress changed to tension after the second stage of drying with air heating. This tension stress became larger in the third stage drying with air heating. In the Link 2, the surface tension stress of the timber after the first stage with air heating changed into compression stress during the second stage with RF heating. However, it has changed into large tension stress in the third stage with air heating again. On the other hand, in the Link 3 the tension stress after the first and second stage drying with air heating has changed into the compression stress at the end of drying. Thus, the surface stress of the sugi boxed heart timber changes into the compression stress by the RF heating in any drying stage. It was presumed that this reason was MC decrease at the inner layer by the concentrated heating

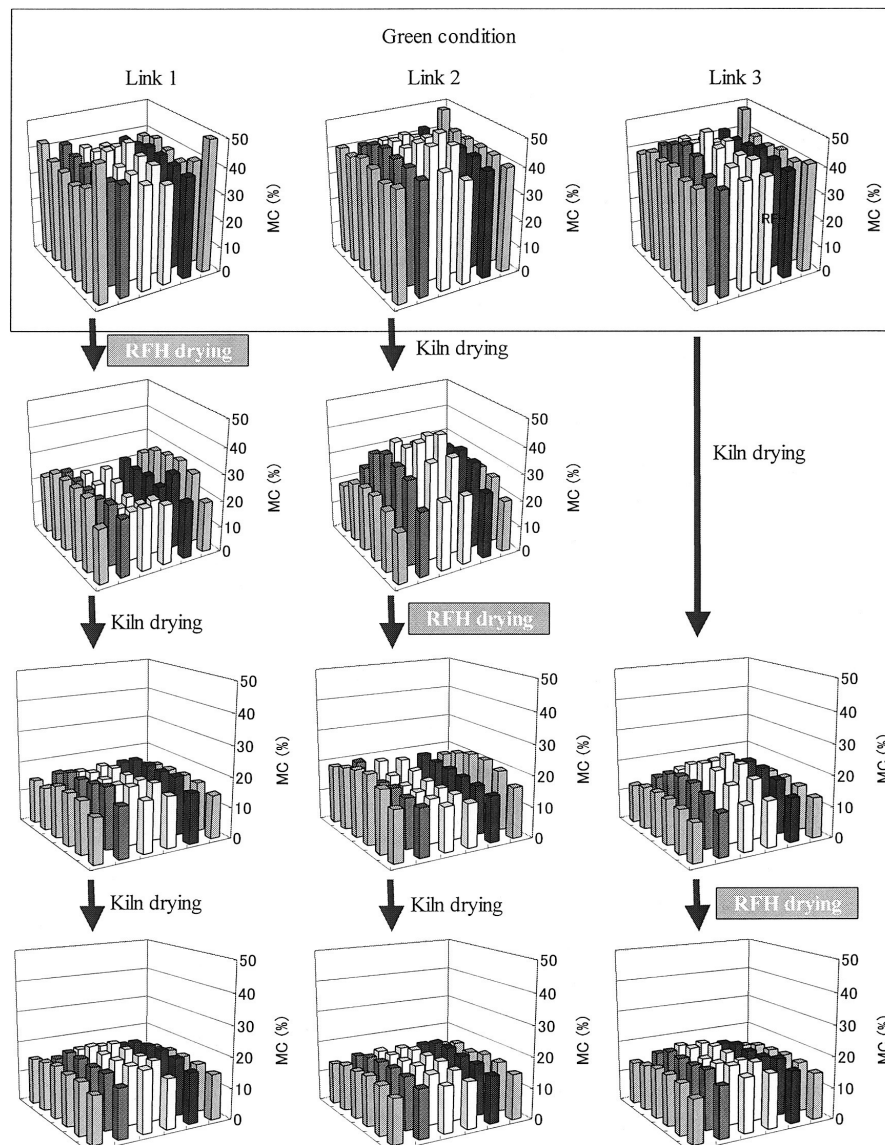


Fig. 4. MC distributions in cross section of the boxed-heart timbers.
Note: RFH: Radio-frequency heating.

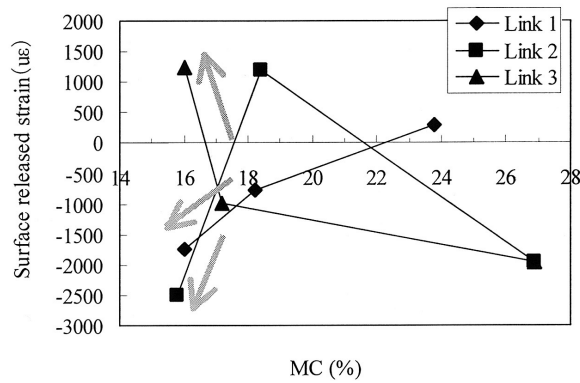


Fig. 5. Change of surface released strain of the boxed-heart timber.

by the RF. However, it seemed that the drying system of the Link 3 was desirable to maintain the quality stability against the surface checks for the dried boxed heart timbers.

Surface checks

Area, length and width of surface checks of the specimens immediately after drying and at the 40th day afterwards are shown in Fig. 6. MCs of all specimens decreased for leaving in the room after drying. The surface checks increased according to the decrease of MC. However, the increase of the width and the area of the surface checks in the Link 3 were comparatively low, and the quality of these boxed heart timbers seemed desirable.

Drying time and multiplication electric power

Drying time and multiplication electric power in these drying systems were shown in Table 2. Drying time in the kiln with air heating in the Link 3 was longer than that in the Link 1 and 2. On the other hand, the amount of electric energy of the RF heating in the Link 3 was fewer than that in the Link 1 and 2. This reason might be the lower thermal capacity of the timbers at the third drying stage with low MC.

CONCLUSIONS

Hybrid kiln drying with RF heating was examined in

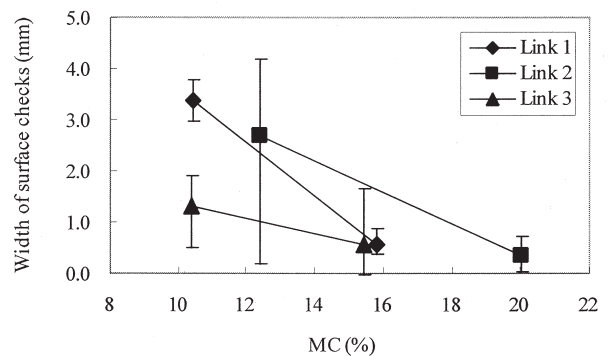
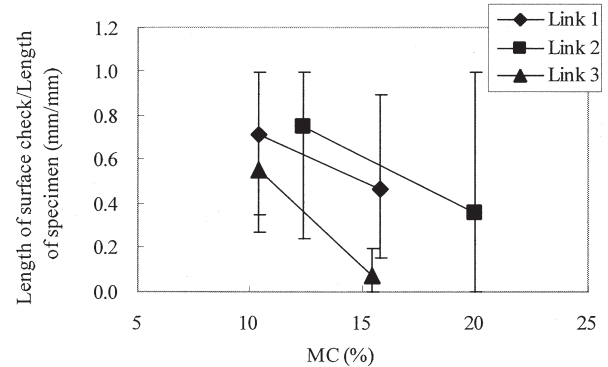
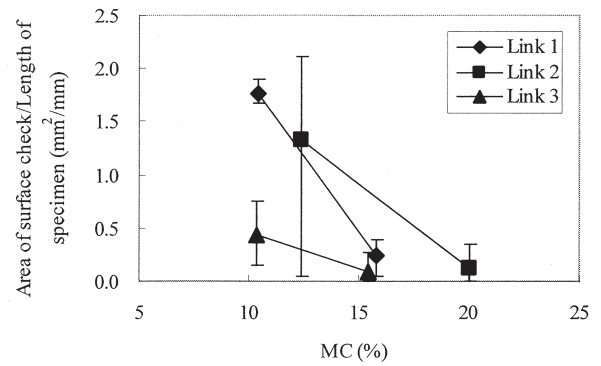


Fig. 6. Change of surface check extent of the timbers left in the room for 40 days after the hybrid kiln drying.

this study.

When the RF heating was applied to initial and the middle term of the drying process (Link 1 and 2), the decrease of MC by the RF heating is remarkable. However, there was no difference of entire drying time among Link 1, 2 and 3. The surface check of Link 3 was

Table 2. Drying time and multiplication electric power of hybrid kiln drying (Link 1, 2 and 3)

	Specimens	MC before drying (%)	MC after drying (%)	irradiation time (h)	multiplication electric power (kwh)	Kiln drying time (h)
Link 1	1-1	49.9	14.9	22.9	7.64	204
	1-2	79.6	15.5			
	1-3	44.9	17			
Link 2	2-1	50.2	15.6	24.6	7.90	214.7
	2-2	107.6	28.6			
	2-3	41.9	15.9			
Link 3	3-1	43.6	15.4	18.2	5.27	240.7
	3-2	91.3	14.4			
	3-3	41.6	16.6			

comparatively small because of tension set formed with the kiln drying at the early stage. Moreover, the RF energy consumption in Link 3 was fewer than in Link 1, 2.

From these results, it was guessed that the hybrid drying system of Link 3 with the RF heating at the latter stage was relatively desirable.

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