Effect of external compressive load during a continuous radio-frequency /vacuum process on movement behavior

Nam-Ho LEE · Young-Moon Jin

Effect of external compressive load during a continuous radio-frequency/vacuum process on movement behavior[*1]

Nam-Ho LEE[*2] · Young-Moon Jin[*3]

ABSTRACT

Movement behavior, shrinkage and equilibrium moisture content (EMC), in this experiment reflected a change of hygroscopicity mainly affected by continuously compressive load during radio-frequency/vacuum (RF/V) drying and humidity changes during equilibrating.

As a result of interaction of the compressive load and moisture content changing under the RF/V condition, the shrinkages in loading direction were significantly increased while those perpendicular to loading direction were decreased. The shrinkages were affected most in tangential, and least in longitudinal direction. The shrinkages showed higher values in continuous drying than in intermittent drying.

In the direction of increased shrinkage, all the movements were also increased, for example, the tangential movement for the loaded-RS and the radial movement for loaded-TS; in the direction of decreased shrinkage, all the movements except the tangential movement for the loaded-TS were decreased such as the tangential and radial movements for the loaded-ES, and the radial movement for the loaded-RS, comparing with those of the load-free.

EMCs of the loaded specimens were all higher than that of the load-free specimen, and the highest for the loaded-TS, the lowest for the loaded-ES.

The transverse hygroscopicity of specimen was reduced for the loaded-ES, but increased for the loaded-TS.

Keywords: ***Radio-frequency/vacuum drying, External compressive load, Shrinkage, Movement, Equilibrium moisture content***

---

*1. 논문접수 ; 2005. 12. 30.

*2. College of Agriculture and Life Science, Chonbuk National University (Institute of Agricultural Science and Technology), Chonju 561-756, Korea

*3. College of Life Science and Natural Resources, Wonkwang University, Iksan 570-749, Korea

1. Introduction

Some researches on the movement of wood under conventional drying condition have been conducted, and some main results of the researches can be described as follows: 1) Tensile stresses in wood induce an increase in moisture content (Libby and Haygreen 1967) while compressive stresses induce a decrease in moisture content (Negi 1999). 2) The effect of mechanical restraint on hygroscopic dimensional changes is very marked in wood because of the large component of rheological or inelastic deformation associated with mechanical stress (Skaar 1988). 3) The so-called permanent set following stressing is largely recoverable when the unloaded wood is taken through repeated cycles of sorption and desorption (Kunesh 1961; Pearson 1981). The recovery of wood after unloading, in fact the accumulated mechano-sorptive strain being vanished (Christensen 1962), is accelerated by moisture cycling and is larger during adsorption than during desorption (Mrtensson 1994). 4) Anisotropy in movement within the transverse plane can be accounted for by the same set of variables that influence shrinkage (Dinwoodie 2000).

In the field of radio-frequency/vacuum (RF/V) drying, the vacuum dried lumber was found to have higher hygroscopicity than kiln dried lumber. Furthermore, the water absorption in cross section of vacuum dried wood was higher than that of kiln dried lumber. Equilibrium moisture content (EMC) was significantly lower in the vacuum dried wood than in conventionally dried wood (Lee and Harris 1984).

But a research on the movement of wood subjected to cyclic humidity changes after dried under RF/V and the restraint of compressive load has not been found. Therefore, to find out shrinking behavior in three fiber directions of wood subjected to compressive load during continuous RF/V drying and subsequent hygro-dimensional change in humidity changes is significant to effectively control the undesirable deformation, check or crack of wood during drying and the dimensional stability in use of final products.

The objective of this study was to investigate that effect of a external compressive load of 0.092 ㎫ on the movement of the Japanese larch specimens in a humidity chamber after continuously dried under RF/V plus external compressive load.

2. Materials And Procedures

2-1 Preparation of Specimens

Four green Japanese larch logs with a length of 1.8 m and an average diameter of 26 ㎝were obtained. Each log was live-sawn into several flitches, and then each flitch from the central part of the log was re-sawn into two squares, each with cross section of 45 x 45 ㎜, from the outer section of the heartwood to minimize the ring curve effect. The squares were surfaced to a final cross sectional size of 40 x 40 ㎜. One of the squares was used for compressive loading and the other for loading-free. Then, an end-matched series of four blocks, each with a length of 40 ㎜ along the grain, was cut from the surfaced square. The four blocks of each end-matched series were, respectively, used for determining shrinkage under continuously compressive loading on the end surface (ES), on the tangential surface (TS), on the radial surface (RS), and under loading-free condition. Twenty-four blocks were prepared for each loading treatment and loading-free, respectively. The average green moisture content (MC) of the blocks was 49.2 %.

2-2 Compressive Loading and Loading-free

The space of a vacuum chamber for this experiment was longitudinally divided into a compressive loading part and a loading-free part (Li, 2004). The blocks stacked in the compressive loading part were compressively loaded with 0.091 ㎫ to 0.093 ㎫ corresponding to an ambient vapor pressure of 8 ㎪ to 10.3 ㎪ in the vacuum chamber, when a vacuum pump was on and off. The pressure, resulting from the difference in absolute pressure between the inside and the outside of the vacuum chamber, was applied to an insulation plate located underneath a flexible rubber sheet with 3 ㎜ in thickness, covering the vacuum chamber, during evacuating the chamber, and transmitted to supporting boards, a top grounded plate, and finally to the blocks stacked in the compressive loading part (Li, 2004). The top load resulting from the insulation plate, the supporting boards, and the grounded plate was considered to be negligible. The blocks in the loading-free part were kept free from compressive loading, by the presence of a void of 24 ㎜ in height between the insulation plate and the top grounded plate, even when a vacuum pump was operating (Li, 2004).

2-3 A Radio-Frequency Heating and Equilibrating Treatment

The blocks were heated by a 7-㎾ Radio-Frequency(RF)generator running on for 8 minutes, and then off for 2 minutes at a fixed frequency of about 13 ㎒. The heating temperature of wood was set at 51.5 ℃. The lengths and weights of blocks were measured just after the continuous RF/V drying process. The RF/V dried blocks were sawn into 5 ㎜ in length along the grain of the blocks for an experiment of equilibrating treatment. The specimens were equilibrated under 90 %, 75 %, and 60 % relative humidity (RH), at 25 ℃. Before and after each equilibrating, the tangential and radial lengths, and weights of specimens were measured.

3. Results And Discussions

3-1 Shrinkage

As previous intermittent drying, the shrinkages in this continuous drying experiment behaved differently in loading directions and also in three fiber directions. The shrinkages in loading directions were significantly increased because a large amount of rheological or inelastic deformation was formed by the compressive load and moisture content changing (Table 1). Although a compressive load of 0.092 MPa is at very low level comparing with previous researches (Hoffmeyer 1993 Wu and Milota 1995), the potential energy of wood molecules could be at higher level due to the energy absorbed in alternating electric field during RF heating, the hydrogen bonds holding the adjacent cellulose chains might be weaker in RF/V drying than in conventional drying, thus the hydrogen bonds can be easily affected by such a low level of load and the amorphous arrangement become looser, more open (Shiraishi et al. 1993). On the other hand, the shrinkages perpendicular to loading directions were decreased because of Poisson radio effects (Table 1). The shrinkages were affected by the load most in tangential, middle in radial and least in longitudinal direction because of mechanical strength of wood being the lowest in tangential, the middle in radial and the highest in longitudinal direction, and microscopic and submicroscopic anisotropy within the tangential and radial walls of longitudinal cell (Naderi and Hernandez 1997).

<**Table 1**> Shrinkage from green to 11 % MC during RF/V drying.

Compressive Loading	Shrinkage(%)				
	Tangential (T)	Radial (R)	T/R	T-R	T+R
Load-free	5.96(4.37)	2.69(2.03)	2.22(2.15)	3.27(2.33)	8.65(6.40)
Loaded-ES	4.84(4.13)	2.57(1.78)	1.88(2.32)	2.27(2.35)	7.41(5.91)
Loaded-TS	4.16(3.54)	4.63(3.02)	0.90(1.17)	-0.47(0.52)	8.79(6.56)
Loaded-RS	10.83(6.70)	1.65(1.11)	6.56(6.03)	9.18(5.59)	12.48(7.81)

Note: The value in brackets was obtained from intermittent drying test (Li, 2004)

Comparing with intermittent drying, the shrinkage in continuous drying exhibited some different trends. On the whole, the shrinkages showed higher values in continuous drying than in intermittent drying. This can be that awning to longer loading duration and less opportunity to release the accumulated stresses as intermittent drying (Chafe 1995), the more rheological deformations might be accumulated during continuous drying than intermittent drying. For the loaded-TS, the radial shrinkage presented unexpectedly high value, even higher than the tangential shrinkage, which might be associated with some collapses in the smallest cell-wall thickness (Tabarsa and Chui 2000, see 1.2), thus T/R and T-R were decreased by 0.27 and 0.99, respectively (Table1).This implies that deformations of squares can be decreased when a compressive load is applied to their tangential surfaces. For the loaded-ES, the radial shrinkage increased more than the tangential shrinkage did, consequently T/R and T-R were decreased by 0.44 and 0.08, respectively (Table 1). Explanation for this is because the tangential expansion is more than the radial expansion when a compressive load is applied parallel to the grain of specimen, and the directions of the expansions are opposite to those of the shrinkages (Burgert et al. 2003).

3-2 Tangential and Radial Movement

The specimen under the condition of restrained shrinkage resulted in a large residual deformation that could amount to 60% of the restrained shrinkage after the fastenings had been removed (Ugolev 1976). The so-called permanent set following stressing was largely recoverable when the unloaded wood was taken through repeated cycles of sorption and desorption (Kunesh 1961; pearson 1981). From above results, it is known that the movement in this experiment can be considered as a result of the accumulated mechano-sorptive strain in restrained shrinkage being recovered under cyclic humidity changes.

<Table 2> Movements at 90 % RH, 75 % RH, and 60 % RH and at 25 ℃.

Compressive loading	Movement(%)								
	(90%RH-60%RH)			(90%RH-75%RH)			(75%RH-60%RH)		
	T	R	T+R	T	R	T+R	T	R	T+R
Load-free	2.42	0.96	3.38	1.10	0.44	1.54	1.34	0.53	1.87
Loaded-Es	2.29	0.90	3.19	1.07	0.45	1.52	1.23	0.46	1.69
Loaded-Ts	2.70	1.21	3.91	1.27	0.57	1.84	1.45	0.64	2.09
Loaded-Rs	2.83	0.88	3.71	1.32	0.39	1.71	1.52	0.50	2.02

In general, the behavior of movement under humidity changes from 90 % RH to 60 % RH was similar to that of the restrained shrinkage except the tangential movement for the loaded-TS (Table 2). In the direction of increased shrinkage, the movements were also increased compared to that of the load-free, probably because the amount of recovered viscous component was increased due to cyclic humidity changes and without mechanical restraint, for example, the tangential movement for the loaded-RS and the radial movement for the loaded-TS (Shiraishi et al. 1993). In the direction of decreased shrinkage, the movements were also decreased comparing with that of the load-free such as the tangential and radial movements for the loaded-ES, and the radial movement for the loaded-RS.

A noticeable observation differing in other responses to humidity changes was that the tangential movement for the loaded-TS appeared quite high value in spite of the least tangential shrinkage for the loaded-TS <**Table 1**>. Pentoney (1953) confirmed a theory proposed by Morath (1932) of greater tangential than radial shrinkage in gross wood of conifers by virtue of the denser summer wood shrinking more than the spring wood. During drying, the tangential shrinkage was most largely restrained due to most increased radial shrinkage under loading on the tangential surfaces of specimen, however, during the equilibrating treatment, the large tangential movement took place due to no mechanical restraint and a potential trend to dimensional change in tangential direction under humidity changes.

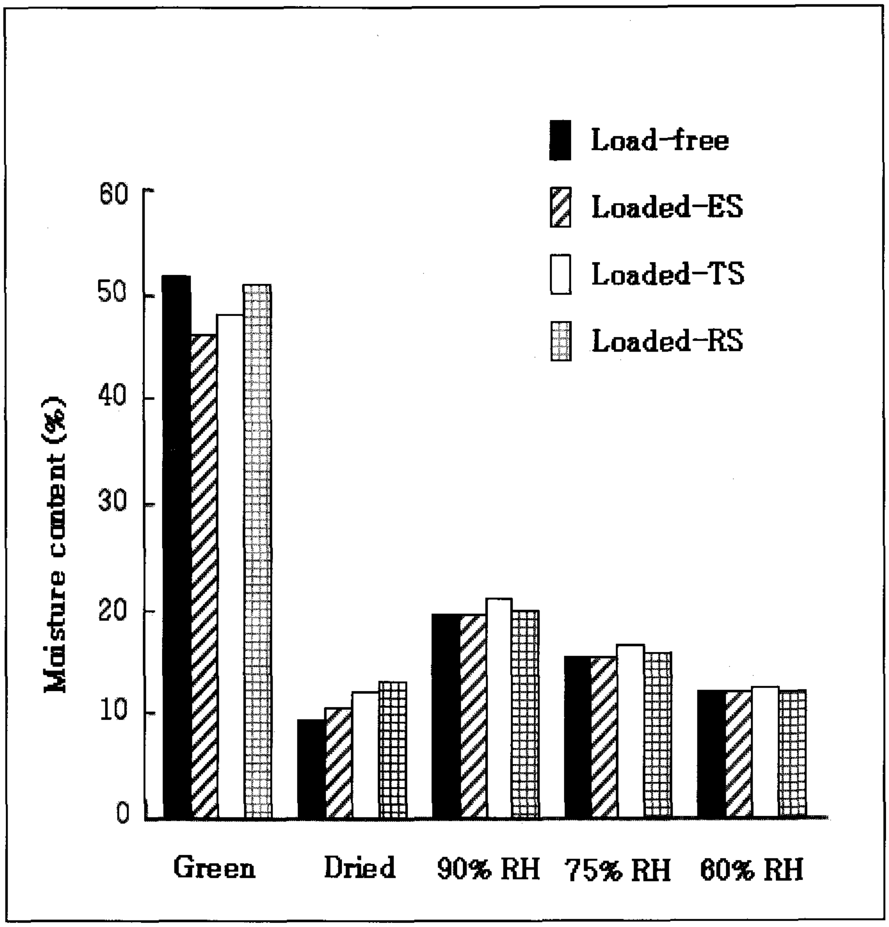
3-3 The Sum of Tangential and Radial Movement

The values of the sum of tangential movements and radial movements were the highest for the loaded-TS, and the lowest for the loaded-ES from 90 % RH to 60 % RH (**Table 2**). These indicate that the transverse hygroscopicity of specimen is reduced for the loaded-ES, but increased for the loaded-TS due to the affection of compressive load. Thus it is advised that a compressive load should be applied to the end surface of log cross section in RF/V drying in order to improve the dimensional stability of final products.

3-4 Equilibrium Moisture Content

The distribution of the equilibrium moisture contents of specimens clearly had two trends (Fig. 1). One was the EMCs of the loaded specimens were slightly higher than that of the load-free specimen from 90 % RH to 60 % RH in spite of their lower MCs at green state. This is disagreement with Lee and Harris (1984) who reported that EMC was significantly lower in vacuum dried wood than in conventionally dried wood. The trend indicates that hygroscopicity of the loaded specimens was increased probably due to there being more amount of viscous deformation inside the specimens because of compressive load (Shiraishi et al. 1993). It could be accounted for that mechanical force increases a certain amount of amorphous regions in loading direction, therefore, a potential of the cell wall of Japanese larch specimen for adsorbing water is increased. The other was that EMCs were the highest for the loaded-TS, the lowest for the loaded-ES, and the middle for the loaded-RS, which could be associated with differences in amount of viscous deformation occurred during shrinking inside the loaded-specimens.

Moreover, according to the hygroelastic effect (Libby and Haygreen 1967; Negi 1999), it can be inferred that there are tensile stresses in transverse direction of the loaded-ES specimen.



<Fig. 1> Moisture content of specimens for green to equilibrating, at 25 ℃

4. Conclusions

Movement behavior, as shrinkage and EMC, in this experiment reflected a change of hygroscopicity mainly affected by compressive load during drying and humidity changes during equilibrating. 1)As a result of interaction of the compressive load and moisture content changing under RF/V condition, the shrinkages in loading direction were significantly increased while those perpendicular to loading direction were decreased. The shrinkages were affected most in tangential, and least in longitudinal direction. 2) The shrinkages showed higher values in continuous drying than in intermittent drying. For the loaded-TS, the radial shrinkage was even higher than the tangential shrinkage, thus T/R and T-R were decreased by 0.27 and 0.99, respectively. For the loaded-ES, the radial shrinkage increased more than the tangential shrinkage did, consequently T/R and T-R were decreased by o.44 and 0.08, respectively. 3) EMCs of the loaded specimens were all higher than that of the load-free specimen, and the highest for the loaded-TS, the lowest for the loaded-ES. 4) In the direction of increased shrinkage, all the movements were also increased, for example, the tangential movement for the loaded-RS and the radial movement for loaded-TS; in the direction of decreased shrinkage, all the movements except the tangential movement for the loaded-TS were decreased such as the tangential and radial movements for the loaded-ES, and the radial movement for the loaded-RS, comparing with those of the load-free. 5) The transverse hygroscopicity of specimen was reduced for the loaded-ES, but increased for the loaded-TS.

5. Literature Cited

1. Burgert, I., T. Okuyama, and H. Yamamoto. 2003. Generation of radial growth stresses in the big rays of konara oak trees. J. Wood Sci. 49 (2): 133.
2. Chafe, S. C. 1995. Preheating and continuous and intermittent drying in boards of Eucalyptus regnans F. Muell. II. Changes in shrinkage and moisture content during drying. Holzforschung. 49 (3): 234-238.
3. Christensen, G. N. 1962. The use of small specimens for studying the effect of moisture content changes on the deformation of wood under load. Aust. J. Appl. Sci. 13 (4): 242-257.
4. Dinwoodie, J. M. 2000. Timber-its nature and behavior. London, U. k. 130-132pp.
5. Hoffmeyer, P. 1993. Non-linear creep caused by slip plane formation. Wood Sci. Technol. 27 (5): 326-327.
6. Kunesh, R. H. 1961. The inelastic behavior of wood. A new concept for

improved panel forming process. Forest Products J. 11: 395-406.

7. Lee, A. W. C., and R. A. Harris. 1984. Properties of red oak lumber dried by a radio-frequency/vacuum process and dehumidification process. Forest prod. J. 34 (5): 56-58.

8. Li C. 2004. Effect of external compressive load on the behavior of shrinkage, tangential strain and movement of woods during radio-frequency/vacuum drying. Theses of Ph. D at Chonbuk National University, Korea: PP 75, pp 79

9. Libby, T. B., and J. G. Haygreen. 1967. Moisture content change induced by tensile stress in whole wood. J. Inst. Wood Sci. 18: 54-60.

10. Mrtensson, A., and S. Svensson. 1997. Stress-strain relationship of drying wood. Holzforschung. 51 (5): 472, 476-477.

11. Mrath, E. 1932. Studien ber die hygroskopischen Eigenschaften und die Hrte der Hlzer. Mitt Holzforsch Darmstadt (cited by Pentony 1953).

12. Naderi, N., and R. E. Hernandez. 1997. Effect of re-wetting treatment on the dimensional changes of sugar maple wood. Wood and Fiber Science. 29 (4): 343.

13. Negi, A. 1999. Turbulence in the wood system with small and short stresses. Wood Science and Technology. 33 (3): 209-214.

14. Pearson, R. G. 1981. In: Adhesion in cellulosic and wood-based composites. Ed. J. F. Oliver. Pienum press. New York and London. 191-209 pp.

15. Pentoney, R. E. 1953. Mechanisms affecting tangential and radial shrinkage. J. For. Prod, Res. Soc. 32: 27-32.

16. Shiraishi, N. et al. 1993. Recent Research on Wood and Wood-based Materials. Kyoto University, Japan. 141-145 pp.

17. Skaar, C. 1988. Wood-Water Relations. Blacksburg, VA, U. S. A. 153-159, 283 pp.

18. Tabarsa, T., and Y. H. Chui. 2000. Stress-strain response of wood under radial compression. Part I. Test method and influences of cellular properties. Wood and Fiber Science. 32 (2): 144-152.

19. Ugolev, B. N. 1976. General laws of wood deformation and rheological proportions of hardwood. Wood Sci. Technol. 10: 169-181.

20. Wu, Q., and M. R. Milota. 1995. Rheological behavior of Douglas-fir perpendicular to the grain at elevated temperatures. Wood and Fiber Science. 27 (3): 288-289.