WOOD RESEARCH
64 (1): 2019
177-184

# DRYING PERFORMANCE OF A DIRECT-FIRED KILN DEVELOPED IN MONGOLIA

Tungalag Ayush, Ayursed Jigjjav, Bayartsetseg Baasan
Mongolian University of Science and Technology, Research and Training
Institute of Forestry and Wood Industry
Ulaanbaatar, Mongolia

Yus Andhini Bhekti Pertiwi
Sebelas Maret University, Facuylty of Agriculture
Surakarta, Indonesia

Futoshi Ishiguri, Shinso Yokota
Utsunomiya University, Faculty of Agriculture
Utsunomiya, Japan

(Received January 2018)

## ABSTRACT

Smoke drying by means of a direct-fired kiln is considered to be one of the most cost-effective methods of drying lumber. In the present study, Siberian larch (*Larix sibirica*) lumber was dried using a direct-fired kiln developed in Mongolia. When approximately 500 kg of sawdust was used as fuel, the maximum and mean temperatures in the kiln were 78.2°C and 54.2°C for the lower side, respectively, while they were 70.4°C and 50.1°C for the upper side, respectively. The temperature inside the kiln was above 60°C for a duration of about 40 to 50 hours. The moisture content of the lumber decreased from 56.4% to 23.2%. No significant differences in terms of the mechanical properties were found between air- and smoke-dried wood. Based on these results, it appears that the direct-fired kiln developed in Mongolia is useful for the low-cost drying of Siberian larch lumber, although improvements to the kiln and a prolonged drying schedule are needed in order to obtain more dried lumber.

KEYWORDS: *Larix sibirica*, direct-fired kiln, smoke drying, mechanical property.

## INTRODUCITON

As of January 1$^{st}$, 2012, forests account for 11.89% (or 18,592,400 ha) of the total territory of Mongolia, with the total forest coverage being comprised of 75.4% deciduous and coniferous forests and 24.6% saxaul (*Haloxylon ammodendron*) forest (FAO 2014a). The most common forest tree species in Mongolia is the Siberian larch (*Larix sibirica* Ledeb.), which accounts for at least 80% of the forest area (Dulamsuren et al. 2010).

The wood industry in Mongolia collapsed following the introduction of a market economy during the 1990s. The share of the gross national product (GNP) of the forestry sector, including the wood processing sector, was 4.1% in 1990, while it was only 0.26% (Ykhanbai 2010). However, the production of industrial round wood is gradually increasing, since it amounted to 49,000 $m^3$ in 2010 and 162,000 $m^3$ in 2014 (FAO 2014b). Due to a move towards the sustainable utilisation of forest resources, the situation of the wood industry in Mongolia has improved. Yet, the further improvement of the forestry sector, including the wood processing sector, in line with the notion of the sustainable utilisation of forest resources is necessary in order to increase economic development in Mongolia.

Drying is one of the important wood processing involved in lumber production. In Mongolia, a low-cost drying method is required for lumber production. One potential low-cost drying method is 'smoke drying'. Using this method, lumber is dried by smoke generated from the burning of sawdust as the fuel in a direct-fired kiln. A direct-fired kiln for 'smoke drying' was first developed in around 1990, and since then it has been used in the wood industry in rural areas of Mongolia. Unfortunately, reliable scientific data concerning the wood industry could not be obtained during the economic confusion following the introduction of a market economy into Mongolia. However, in the United States, Boone et al. (1988) noted that direct-fired kilns are mainly used for drying softwood dimension lumber for use in the construction industry, although it remains very difficult to control the moisture content during the drying operation. In Japan, several studies have focused on the 'smoke heating' of logs by direct-fired kilns as a pretreatment prior to drying (Okuyama et al. 1987, Tejada et al. 1997, Ishiguri et al. 2003). Reduction in the moisture content and residual stress was achieved in these studies by heating the logs so that the temperature inside the logs reached between 80°C and 100°C (Okuyama et al. 1987, Tejada et al. 1997, Ishiguri et al. 2003, Nogi et al. 2003). In addition, an increase in the Young's modulus due to an increase in cellulose crystallinity as well as a decrease in the equilibrium moisture content was also recognised in the wood after smoke heating (Ishiguri et al. 2003).

This is the first scientific report to evaluate the drying performance of a direct-fired kiln developed in Mongolia. In the present study, in order to obtain both the appropriate drying conditions and knowledge relevant to the future improvement of the kiln, Siberian larch lumber was dried using a commercial direct-fired kiln developed in Mongolia. In addition, the effect of smoke drying on the mechanical properties of the wood was also evaluated.

## MATERIALS AND METHODS

Fig. 1 presents an illustration of the commercial direct-fired kiln used in this study. The kiln was built underground due to the severe climatic conditions experienced during the winter season in Mongolia. Only the roof, which included a door, and chimneys were located at ground level. The kiln was approximately 4.7 m in length between the chimneys, while it was 4.3 m in length between the intakes, and 4.0 m in height. The sawdust fuel was placed in a furnace located in the bottom of the kiln. Three rails were set in place for lumber stacking approximately 1.2 m from the bottom of the kiln.

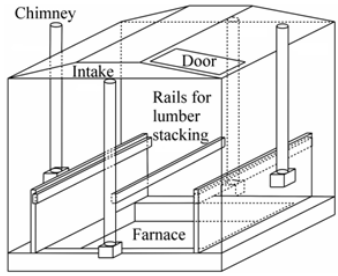


*Fig. 1: Illustration of the direct-fired kiln used in the present study.*

In the present study, a total of 520 kg of sawdust (wet basis moisture content = 11.8%–22.4%) was used as fuel. A total of 117 pieces (4000 x 150 x 50 mm) of green Siberian larch (*Larix sibirica*) were used in this experiment. Fifteen pieces of lumber were stacked in each layer on the rails. Due to the limited amount of sample lumber, only 12 pieces of lumber were placed in the highest layer. The utilised stickers were the same size as the lumber used in the experiment. Three stickers were used between each of the layers. The temperatures inside both the kiln and the lumber were recorded at the highest and lowest parts of the stacked lumber using a data logger (Hakusan, LS-3000) and a thermocouple every 10 min. During the drying process, only the intake of the kiln was operated.

The following properties were determined for all the pieces of lumber before and after the drying process: weight, dimensions, moisture content, warp and dynamic Young's modulus. The moisture content was determined using a moisture meter (Kett, HM-520), while the dynamic Young's modulus of the lumber was determined by means of the tapping method (Sobue 1986) with an FFT analyser (A&D, AD-3527) and an accelerometer (Rion, PV-85). From the total of 117 pieces of lumber, specimens for determining the moisture content by means of the oven-dry method were collected from 23 pieces of lumber.

In order to evaluate the effects of smoke drying on the mechanical properties of the wood, end-matched samples were prepared. Three pieces of lumber of 4000 mm in length were each cut into pieces some 500 mm and 3500 mm in length. The three pieces of lumber that were 500 mm in length were then air-dried as control samples, while the three pieces of lumber that were 3500 mm in length were smoke-dried. Following the air-drying of the samples, two types of small-clear specimens were prepared, namely 10 (R) by 10 (T) by 160 mm specimens for the static and impact bending tests, and 10 (R) by 10 (T) by 40 mm specimens for the compressive test. The static bending test was performed using a universal testing machine (Tokyo Testing Machine, MSC-5/500-2). A load was applied at the centre of the specimen at a rate of 5 $mm \cdot min^{-1}$. The modulus of elasticity (MOE) and the modulus of rupture (MOR) were then calculated. The impact bending test was conducted using a Charpy-type impact test machine (Toyo Kogyo Seisakusho) with a 65 mm span, 16.6 N of pendulum weight, 400 mm in distance from the centre of the supporting axis to the centre of gravity of the pendulum, and a 125° initial angle of the pendulum. The absorbed energy in impact bending was calculated. The compressive test was conducted using a universal testing machine (A&D, RTF-2350). A load was applied to the specimen parallel to the grain at a rate of 0.5 $mm \cdot min^{-1}$. The compressive strength parallel to the grain was then calculated from the maximum crushing strength and the cross-sectional area of the specimen.

In order to detect any significant differences in the lumber's properties before and after drying, as well as the mechanical properties of the small-clear specimens obtained from the air- and smoke-dried lumber, a t-test was applied for each property using R software (R Core Team 2015).

## RESULTS AND DISCUSSION

Fig. 2 shows the changes in temperature observed throughout the drying process. During the drying, the mean outside temperature was 12.3°C (minimum 2.1°C, and maximum 28.2°C, respectively). The maximum and mean temperatures in the kiln were 78.2°C and 54.2°C for the lower side, respectively, and 70.4°C and 50.1°C for the upper side, respectively. Further, the maximum and mean temperatures of the lumber were 79.1°C and 53.5°C for the lower layer, respectively, and 62.1°C and 44.1°C for the upper layer, respectively. The maximum temperature differences between the lower and upper layers were 7.8°C and 17.0°C for the kiln and the lumber, respectively.

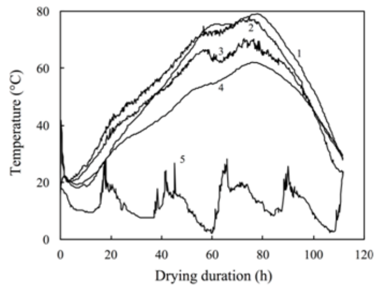


*Fig. 2: Changes in temperature of the kiln and the lumber during drying: 1- kiln at upper side; 2- kiln at lower side (near the rail for stacking in Fig. 1); 3- lumber at upper layer; 4- lumber at lower layer; 5- outside temperature.*

Tab. 1 shows the changes in the lumber's properties caused by the drying process. The weight, wood density and moisture content were all significantly decreased after drying.

*Tab. 1: Changes in the lumber properties before and after drying.*

| Property | Before drying (n = 117) | | | | After drying (n = 117) | | | | Significant |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Min. | Max. | Mean | SD | Min. | Max. | |
| Weight (kg) | 23.0 | 2.6 | 18.0 | 32.1 | 18.1 | 2.2 | 13.9 | 25.6 | ** |
| Wood density (kgm$^{-3}$) | 757 | 87 | 578 | 1024 | 613 | 70 | 478 | 797 | ** |
| $MC_1$ (%) | 56.4 | 12.7 | 34.5 | 98.0 | 23.2 | 4.9 | 10.3 | 37.0 | ** |
| $MC_2$ (%) | 37.1 | 10.2 | 22.1 | 64.6 | 27.0 | 7.6 | 20.5 | 53.3 | ** |
| Crook (%) | 0.12 | 0.07 | 0.00 | 0.38 | 0.17 | 0.13 | 0.02 | 0.60 | ** |
| Bow (%) | 0.15 | 0.09 | 0.00 | 0.69 | 0.32 | 0.20 | 0.05 | 1.13 | ** |
| DMOE (GPa) | 8.91 | 1.59 | 5.68 | 13.56 | 9.03 | 1.45 | 5.38 | 12.03 | ns |

Note: n- number of lumber; SD- standard deviation; $MC_1$- moisture content determined by moisture meter; $MC_2$- moisture content determined by oven-dry method; DMOE - dynamic Young's modulus; ** - significance at 1% level; ns- no significance at 1 or 5% level, number of lumber = 23.

The moisture content, as determined by the moisture meter, decreased from 56.4% to 23.2%. The results were similar to those determined according to the oven-dry method (a decrease from 37.1% to 27.0%). Based on these results, it appears that the moisture content of the lumber might be around 25% after drying. Although the moisture content was not decreased below the fibre saturation point, relatively larger values were found in both the crook and the bow.

According to Boone et al. (1988), the time-controlled schedules of larch (*Larix lyallii* and *Larix occidentalis*) lower the grade of the lumber by 25 mm to 50 mm according to conventional temperatures when the dry-bulb temperature is set at 82°C for up to 84 hours. In addition, when Siberian larch lumber of 50 mm in thickness obtained from Finland and Siberia was dried at a dry-bulb temperature of 60°C for 357 h (including the conditioning and cooling time) using a conventional kiln, the mean ± standard deviation of the moisture content of the lumber ranged from 9.4 ± 1.6% to 13.7 ± 1.9% (Heikkonen et al. 2007). In the present study, the temperature inside the kiln was only above 60°C for a duration of about 40 to 50 hours (Fig. 2). Therefore, the moisture content only decreased to around 25%.

In the present study, we evaluated the drying performance of a commercial direct-fired kiln developed in Mongolia. When approximately 500 kg of sawdust was used as fuel, the mean temperature inside the kiln reached about 50°C, while the temperature inside the kiln was above 60°C for a duration of about 40 to 50 hours. These results suggest that the drying duration should be prolonged in order to decrease the moisture content of the lumber. In addition, a large temperature difference between the lower side and the upper side was recognised. This result indicates that the temperature distribution inside the kiln was not uniform. In fact, a greater decrease was seen in the ratio of the weight of the lumber in the lower layers when compared to that seen in the upper layers (Tab. 2).

*Tab. 2: Changes of weight of lumber in each layer.*

| **Layer** | | **n** | **Weight of lumber (kg)** | | | | **Decrease ratio (%)** |
|---|---|---|---|---|---|---|---|
| | | | **Before drying** | | **After drying** | | |
| | | | **Mean** | **SD** | **Mean** | **SD** | |
| **Upper** | 8 | 12 | 21.8 | 1.6 | 17.8 | 1.2 | 18.5 |
| | 7 | 15 | 23.4 | 2.7 | 18.8 | 2.4 | 19.7 |
| | 6 | 15 | 22.3 | 1.6 | 17.8 | 1.8 | 20.1 |
| | 5 | 15 | 23.1 | 2.6 | 18.2 | 2.0 | 21.1 |
| | 4 | 15 | 22.6 | 2.9 | 18.0 | 2.7 | 20.4 |
| | 3 | 15 | 23.1 | 2.4 | 17.8 | 1.7 | 23.0 |
| | 2 | 15 | 24.0 | 2.9 | 19.0 | 2.7 | 20.9 |
| **Lower** | 1 | 15 | 23.6 | 3.1 | 17.4 | 2.6 | 26.0 |

Note: n- number of lumber in each layer; SD- standard deviation.

Therefore, it is suggested that both a wall between the furnace and the rails used for stacking the lumber and an internal fan or similar equipment are needed to improve the uneven distribution of the temperature inside the kiln. Yet, significant correlations were not found between the outside temperature and the temperature of the kiln or lumber (Tab. 3), which suggests that the outside temperature might be not related to the temperature within the kiln even if the outside temperature reaches a minimum of around 0°C (Fig. 2). Thus, this direct-fired kiln might be used during the winter season in Mongolia when the temperature reaches -20°C or colder. However, further research is needed to determine a suitable drying schedule.

*Tab. 3: Correlation coefficients between outside temperature and kiln or lumber temperatures.*

| **Position** | | **Correlation coefficient** |
|---|---|---|
| **Kiln** | **Upper** | 0.134 ns |
| | **Lower** | 0.182 ns |
| **Lumber** | **Upper** | 0.137 ns |
| | **Lower** | 0.114 ns |

Note: n- no significance at 5 or 1 % level.

Tab. 4 shows the mechanical properties of the smoke-dried wood. No significant differences were found in any of the mechanical properties between the air- and smoke-dried wood. Similar results were also obtained in relation to the dynamic Young's modulus of the lumber (Tab. 1).

*Tab. 4: Mechanical properties of small-clear specimens.*

| Property | Air drying | | | Smoke drying | | | Significant |
|---|---|---|---|---|---|---|---|
| | n | Mean | SD | n | Mean | SD | |
| **MOE (GPa)** | 26 | 9.20 | 1.33 | 31 | 10.38 | 3.67 | ns |
| **MOR (MPa)** | 26 | 99.5 | 13.6 | 31 | 100.3 | 9.6 | ns |
| **CS (MPa)** | 23 | 55.5 | 7.4 | 26 | 53.0 | 11.3 | ns |
| **IB ($J \cdot cm^{-2}$)** | 25 | 3.084 | 0.957 | 30 | 2.645 | 0.940 | ns |

Note: n- total number of specimens from three sample lumbers; SD- standard deviation; MOE- modulus of elasticity; MOR- modulus of rupture; CS- compressive strength parallel to grain; IB- absorbed energy in impact bending; ns- no significance at 5 or 1 % level. Moisture content of the specimens ranged from 6.7 to 8.7%.

It has previously been reported that no significant thermal degradation of the wood occurred due to heat treatment when the logs were heated for 60 h so that the temperature inside the logs was 80°C (Ishiguri et al. 2003). In the present study, the maximum lumber temperature was below 80°C. Therefore, no significant change in the mechanical properties was found between the air- and smoke-dried wood.

## CONCLUSIONS

In the present study, in order to evaluate the drying performance of a direct-fired kiln developed in Mongolia, Siberian larch lumber was smoke-dried using the kiln. In addition, the effects of smoke drying on the mechanical properties of the wood were also evaluated. When approximately 500 kg of sawdust was used as fuel and the average outside temperature was 12.3°C, the maximum and mean temperatures of the lumber were 79.1°C and 53.5°C for the lower layer, respectively, and 62.1°C and 44.1°C for the upper layer, respectively. The temperature inside the kiln was above 60°C for duration of approximately 40 to 50 hours. The moisture content, as determined by the moisture meter, decreased from 56.4% to 23.2%. No significant differences in any of the mechanical properties were found between the air- and smoke-dried wood. Based on these results, it is concluded that the direct-fired kiln developed in Mongolia can be used for the low-cost drying of larch lumber, although further research is required to determine both the most appropriate drying schedule and the improvements that could be made to the kiln in order to decrease the temperature differences inside it.

## ACKNOWELDGEMENTS

Part of this research was financially supported by the M-JEED program of the Ministry of Education, Culture and Science, Mongolia. The authors wish to express their appreciation to Sarkhad Murzabek and Biligt Battuvshin, Mongolian University of Science and Technology, Mongolia, and Ei Igarashi, Utsunomiya University, Japan, for their assistance with the drying experiments.

## REFERENCES


1. Boone, R.S., Kozlik, C.J., Bois, P.J., Wengert, E.M., 1988: Dry kiln schedules for commercial woods: temperate and tropical. Gen Tech Rep FPL-GTR-57. USDA ForServ Forest Products Laboratory. http://www.fpl.fs.fed.us/documnts/fplgtr/fplgtr57.pdf. (23 Aug 2016).
2. Dulamsuren, C., Hauck, M., Khishigjargal, M., Keuschner, H.H., Lenschner, C., 2010: Diverging climate trends in Mongolian taiga forests influence growth and regeneration of *Larix sibirica*, Oecologia 163: 1091-1102.
3. FAO 2014a: Global forest resources assessment 2015, country report, Mongolia. http://www.fao.org/3/a-az278e.pdf. (27 Aug 2016).
4. FAO 2014b: FAO yearbook of forest products 2014. http://www.fao.org/3/a-i5542m.pdf.(31 Aug 2016).
5. Heikkonen, S., Luostarinen, K., Piispa, K., 2007: Kiln drying of Siberian larch (*Larix sibirica*) timber. https://www.mamk.fi/instancedata/prime_product_julkaisu/mamk/embeds/mamkwwwstructure/14146_1473-844-verkko_heikkonen.pdf. (27 Aug 2016).
6. Ishiguri, F., Matsui, M., Andoh, M., Yokota, S., Yoshizawa, N., 2003: Time-course changes of chemical and physical properties in sugi (*Cryptomeria japonica* D. Don) logs during smoke heating, Wood and Fiber Science 35(4): 585-593.
7. Nogi, M., Yamamoto, H., Okuyama, T., 2003: Relaxation mechanism of residual stress inside logs by heat treatment: choosing the heating time and temperature, Journal of Wood Science 49: 22-28.
8. Okuyama, T., Kanagawa, Y., Hattori, Y., 1987: Reduction of residual stresses in logs by direct heating method, Mokuzai Gakkaishi 33: 837-843.
9. R Core Team. 2015: R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/. (21 July 2015).
10. Sobue, N., 1986: Measurement of Young's modulus by the transient longitudinal vibration of wooden beams using a fast Fourier transformation spectrum analyzer, Mokuzai Gakkaishi 32(9): 744-747.
11. Tejada, A., Okuyama, T., Yamamoto, H., Yoshida, M., 1997: Reduction of growth stress in logs by direct heat treatment: assessment of a commercial-scale operation, Forest Products Journal 47(9): 86-93.
12. Ykhanbai, H., 2010: Mongolia forestry outlook study. http://www.fao.org/3/a-am616e.pdf. (31 Aug 2016).



Tungalag Ayush, Ayursed Jigjjav, Bayartsetseg Baasan
Mongolian University of Science and Technology
Research and Training Institute of Forestry and Wood Industry
8th Khoroo, Baga Toiruu 34
Sukhbaatar District
Ulaanbaatar14191
Mongolia

Yus Andhini Bhekti Pertiwi
Sebelas Maret University
Faculty of Agriculture
Surakarta 57126
Indonesia

*Futoshi Ishiguri, Shinso Yokota
Utsunomiya University
Faculty of Agriculture
Utsunomiya 321-8505
Japan
*Corresponding author: ishiguri@cc.utsunomiya-u.ac.jp
Phone: +81 28 649 5541