九州大学学術情報リポジトリ
Kyushu University Institutional Repository

# Investigation on Durability of Japanese Cedar (Cryptomeria japonica) Laminated Veneer Lumber

SHIAH, Tsang-Chyi
Department of Wood Based Materials and Design, College of Agriculture, National Chiayi University

LIN, Li-Sheng
Master, Graduate Institute of Wood Based Materials and Design, College of Agriculture

FUJIMOTO, Noboru
Laboratory of Wood Material Technology, Division of Sustainable Bioresources Science, Department of Agro-environmental Sciences, Faculty of Agriculture, Kyushu University

LIN, Han Chien
Laboratory of Environment Functional Materials, Department of Wood Based Materials and Design, College of Agriculture, National Chiayi University

https://doi.org/10.5109/4772337

出版情報：九州大学大学院農学研究院紀要. 67 (1), pp.17-23, 2022. Faculty of Agriculture, Kyushu University
バージョン：
権利関係：

J. Fac. Agr., Kyushu Univ., **67** (1), 17–23 (2022)

# Investigation on Durability of Japanese Cedar (*Cryptomeria japonica*) Laminated Veneer Lumber

**Tsang–Chyi SHIAH[1], Li-Sheng LIN[2], Noboru FUJIMOTO and Han Chien LIN[3]***

Laboratory of Wood Material Technology, Division of Sustainable Bioresources Science,
Department of Agro–environmental Sciences, Faculty of Agriculture,
Kyushu University, Fukuoka 819–0395, Japan
(*Received October 30, 2021 and accepted November 5, 2021*)

*Cryptomeria japonica* (Japanese cedar, JC) was prepared into veneers and mass–produced into laminated veneer lumber (LVL), and the residual cores from the rotary cutting of the log were employed as the test specimens and compared with that of *Pinus radiate* (Radiata pine, RP). The *Aspergillus niger*, *Aspergillus flavus*, and the *Laetiporus sulphureus* of brown–rot fungi, the *Lenzites betulina* of white–rot fungi were used to test the fungi and decay resistance. The residual cores were buried in the field, and the LVLs were placed in the outdoor corridor to evaluate the natural durability. The resistance to microbial deterioration of various specimens was investigated. The JC veneer had better fungi resistance than RP, with a significant difference between them. The perpendicular direction of JC LVL had a higher fungal growth rate than that of the RP, but there was no significant difference. According to the decay resistance results of white-rot fungi, there were insignificantly between the weight loss rate of JC veneer, parallel direction of JC LVL, and perpendicular direction of JC LVL, and those of RP. The weight loss rate of parallel direction and perpendicular direction of JC LVLs evaluated by brown–rot fungi was only half of the RP. After the burial test in the field of 18 months, the weight retention rate of the residual cores after the rotary cutting of log was 92.74%, whereas that of RP was 52.79% with its core specimens showing a biological deterioration appearance obviously. After the durability test of 36 weeks in the outdoor corridor, the weight loss rates of JC and RP LVLs were 4.11 and 8.31%, respectively. The JC LVL had a better resistance to microbial deterioration and natural durability than the RP.

**Key words**: *Cryptomeria japonica* (Japanese cedar, JC), *Pinus radiate* (Radiata pine, RP), Laminated Veneer Lumber (LVL), Durability

## INTRODUCTION

Since 1992, Taiwan has thoroughly prohibited cutting natural forests, turning the forest policy to forest conservation. The average annual demand for wood remains at about 6,000,000 m$^3$, whereas the supply volume of domestic timber is only 40,000 to 60,000 m$^3$ (Taiwan Forest Bureau, 1995 and 2016). In order to attain the goals favorable for comprehensive development, such as strengthening forest land management, enhancing homeland security, and promoting multiple utilization of forest resources. The Council of Agriculture, Executive Yuan promoted "the Sustainable Operation of Forests and Industrial Revival Program" for domestic timber production planning and market development to consolidate the industry chain and generalize domestic timber brand marketing and forest byproduct business in Taiwan. Meanwhile, the Forestry Bureau defined the year 2017 as "the first year of domestic timbers", pushing them in the market with the hopes of increasing a self-sufficient ratio. At present, one of the major coniferous species of domestic timber is *Cryptomeria japonica* (Japanese cedar, JC). According to the fourth nationwide forest resources survey statistics, the total amount of growing stock of JC is about 7,690,000 m$^3$ (Taiwan Forest Bureau, 2016). Furthermore, given that most of them include medium and small diameter wood, the manner of enhancing its usage and supply has become one of the important topics of current forest management and forest product utilization. However, in the precondition of forest conservation, the domestic JC timber has poor properties, where using wood–based materials may promote its utilization rate and improve its properties.

Recently, the application of wood–based materials has not been restricted to the interior anymore. Some outdoor planking and lightweight construction timber wood have been gradually substituted by the modified solid wood or wood–based materials for their appearance and specific strengths. The purpose is to enhance materials' resistance to biological deterioration to extend their service life. Among wood–based materials, the LVL is the most similar material simulating tree growth and proximity to wood's natural characteristics (Kamala *et al.*, 1999; Wang and Dai, 2005). It is a glued construction with a unidirectional laminated wood figure, which can remedy the defects present in natural wood (e.g., knots, decay, etc.) and increase density (decrease porosity). In addition, it is more homogeneous than solid wood structures and is resistant to warpage, cracking, and shrinkage. It therefore can increase the timber utilization rate (Robbins, 1989). The LVL can be produced into boards conforming to specific strength and size, making it applicable to mass production. As the value is increased due to improved properties, some of internal

[1] Department of Wood Based Materials and Design, College of Agriculture, National Chiayi University, Chiayi, Taiwan, ROC
[2] Master, Graduate Institute of Wood Based Materials and Design, College of Agriculture, Chiayi, Taiwan, ROC
[3] Laboratory of Environment Functional Materials, Department of Wood Based Materials and Design, College of Agriculture, National Chiayi University, Chiayi, Taiwan, ROC
* Corresponding author (E–mail: alexhlin@mail.ncyu.edu.tw)

constructions are for the development of utilization (Ozarska, 1993). Presently, the log for making plywood and LVL in Taiwan is mostly *Pinus radiate* (Radiata pine, RP). It has a straight texture, uniform structure, and high stability; it has good workability and is easy to dry and coating. However, as it grows rapidly, the mechanical strength of the wood is lower than that of other lumber products of the same grade due to a higher proportion of pith wood. Moreover, as the RP is easily to rot in highly humid environments (Morita *et al.* 1991), its utilization rate is increased generally by using rot–proof timbers treated with preservatives (Nzokou *et al.*, 2005).

Both the JC and RP are ranked as type IV among the common coniferous species of structural timber (National Standards of the Republic of China; CNS 14630, 2017). As the use of wood is not restricted to the interior anymore, the outdoor environment is more rigorous than the indoor one. This is because climate change, resulting in high temperature and humidity, and biological attacks, causes irretrievable damage to the wood. On the other hand, the damages of fungi, rot-fungi, and termites apparently influence the appearance of wood–based materials and degrade their usability and strength quality. The outdoor applicability is explored and learned by discussing the resistance to biological deterioration of JC and RP. Morita *et al.* (1997) studied the composition of antifungal extracts of JC. The result indicated that the JC heartwood essential oil and methanol extracts had a good inhibitory effect on the activity of wood–decaying fungi and phytopathogen, and the hexane soluble part of sapwood was active in resisting vector mosquito larvae. Sogabe *et al.* (2000) obtained bio–resistant compounds from the JC heartwood. As stated above, the JC contains different antifungal and insect resistant extracts. However, in the course of making it into LVL, the drying, veneering, and hot pressing may change some of the original properties, it can be accessible to LVL.

Therefore, in response to the government's advocacy of using domestic timber, this study investigated the resistance to microbial deterioration of domestic JC veneer and mass–produced LVL, comparing that of the commercially available RP veneer and LVL. The veneers of the two species and different directions of LVLs were employed to evaluate the resistance to microbial deterioration, including the tests for fungi resistance, decay resistance of veneer and LVL, the natural durability of burial cores in the field and placing LVL in outdoor corridors. This study aims to determine the difference between the JC and RP regarding their resistance to microbial deterioration and applicability to outdoor environments, in order to provide a future reference in using the LVL mass–produced from JC.

## MATERIALS ANDMETHODS

### Test materials

The about 44–year–old thinned JC log provided by the Forestry Bureau of Taiwan and the about 20–year–old RP imported from Chile provided by a local company of Wand Tsai Industrial Co., LTD. (WTS) were adopted as the test specimens. Both were mass–produced by WTS into veneer and 9–ply LVL. The absolute–dried specific gravity of JC veneer was 0.32, while its moisture content was 9.06%. The absolute-dried specific gravity of RP was 0.37, while its moisture content was 9.91%. The absolute–dried specific gravity and moisture content of JC LVL were 0.36 and 12.03%, respectively. And, those of RP were 0.51 and 9.88%, respectively. Taking the surface plane of LVL as the reference plane, the LVL was divided into parallel and perpendicular directions. The veneering line parallel with the reference direction was the parallel direction of specimen, and the veneering line vertical to the reference direction was the perpendicular direction of specimen. The residual cores in diameter of about 50 mm after the JC and RP logs were prepared into veneers by rotary cutting were used as the test specimens for the burial test in the field. Furthermore, the moisture content of JC residual core was 83.05%, while that of RP residual core was 31.54%.

### Test method

*Fungi inoculation and fungal resistance*

The CNS 16065 (2018) Method of test for fungus resistance of wood and bamboo was adopted for this experiment with some modifications. The veneer size of 30×30×3 mm and the LVL size of 30×30×10 mm were each tested three times on the parallel and perpendicular direction of LVL. The 2 strains of fungi used were *Aspergillus niger* and *Aspergillus flavus*, and the fungi from air borne spores (airborne fungi particles) were used as one of the tested strains.

The first step was to prepare spore suspension, instill 20 mL aseptic water in the species culture medium on a sterile console, gently push the species surface with a glass rod to mix the aseptic water with spores, and suck the mixed liquor into 200 mL aseptic water as control liquor. The quantity of spores in the control liquor was calculated by optical microscope and blood counting plate, while the spore suspension concentration was adjusted to $10^{4-5}$ spores/mL. Afterward, the plating medium was prepared, 39 g potato dextrose agar was added in 1000 mL distilled water and stirred thoroughly to make a culture medium. This was sterilized with 121ºC of temperature in a sterilization kettle for 1.5 h, then taken out and was poured when it cooled down to about 60°C. Notably, all plating media have to be irradiated by UV in the sterile console for about 8 h. When the plating medium was sterilized, the specimen was irradiated by UV in the sterile console for 24 h. Then, it was placed in the plating medium of about 25 $\mu$L.

*Aspergillus niger* and *Aspergillus flavus* spore suspensions were sucked by pipette on the sterile console and inoculated on the surface of each test piece. The culture dish was closed and taken out of the sterile console and sealed with parafilm. In terms of the airborne fungi particles, the culture dish with specimen was closed and taken out of the sterile console, which the upper cover was opened and was closed 30 min later and sealed with parafilm. Further, it was placed in the wooden house classroom by the wood utilization factory of National Chiayi University (NCYU) in Taiwan. All the inoculated culture dishes were placed in the 25°C incubator for the test. The test period was 1 week, where the growth condition of various species was observed macroscopically every day, while the growth rate (%) of two of strains was observed on 100% specimen surface.

*Decay resistance test*

The CNS 15697 (2013) Wood – Determination of decay resistance was modified for testing. The veneer and LVL sizes were 50×50×3 mm and 20×20×20 mm, respectively, with parallel and perpendicular directions. Each of the specimens was tested for three times. The JC and RP veneers and LVLs were dried in the oven at 60±2°C for 48 h, and their weights were measured. The specimens were inoculated with *Laetiporus sulphureus* of brown–rot fungi and *Lenzites betulina* of white–rot fungi.

Additionally, the plating medium preparation method was same as above fungi test. The culture dish must be loaded with 25 g fine sand before the culture medium was poured into it. The fine sand, used for simulating the natural environment, was sieved to 10 mesh, sterilized with 121°C of temperature in a sterilization kettle for about 1.5 h, and dried. The fine sand plating medium and test piece were irradiated by UV on the sterile console for about 8 h and 24 h before the test. The inoculation was performed on the sterile console, while the specimen was placed in the fine sand plating medium at about 25 $\mu$L. White–rot fungi and brown–rot fungi spore suspensions were sucked by pipette and inoculated on the surface of specimens. The culture dish was covered and taken out of the sterile console and sealed with parafilm. Completed culture dishes were all put in the incubating chamber at a temperature of 26±2°C and relative humidity (RH) of 85%.

The growth condition of two species with various specimens was observed at around a 5–day interval. Since Day 30, the specimens were drawn randomly every 10 days, where three specimens were drawn from JC and RP. With 36 specimens, the sampling was performed three times with a test period of 60 days. When the specimens were taken out, the thalli adhering to its surface were brushed away and placed in the oven at 40±2°C for 24 h. The temperature was increased to 60±2°C and dried for 48 h. The specimens were taken out and weighed, of which the weight loss rate (WL, %) was calculated according to the equation WL (%) =[($W_1$–$W_2$ /$W_1$)*100], $W_1$: absolute–dried weight (g) of specimen before the test; $W_2$: absolute–dried weight (g) of specimen after the test.

*Natural durability test for field buried residual core*

With some modifications, the CNS 15756 (2014) Wood–Test methods for determining termite resistance was employed for this part of the experiment. For the weight loss of specimen in the field environment, the residual core was the radial wood with a diameter of about 50 mm after the log was prepared into veneers by rotary cutting. The radial wood was at least 400 mm long before sawing and was sawn into 50 mm and 350 mm specimens. The moisture content in the 350 mm piece of the same radial wood was calculated from the 50 mm piece. The air–dried weight of 50 mm specimens of JC and RP was measured. They were then put in the oven at 103±2°C for 24 h to measure the absolute–dried weight. The moisture content was calculated according to the equation (CNS 452–2013). Similarly, the absolute–dried weight of the 350 mm specimen was calculated. The weight loss rate was calculated according to the results. The 350 mm specimens of JC and RP were tested for six times.

The test site for the natural durability of field–buried wood was nearby the wood utilization factory of NCYU in Taiwan. A soil drilling machine was adopted for drilling; the holes were longitudinally and transversely spaced apart for about 300 mm, each hole about 300 mm deep. Six residual core specimens of JC and RP were taken as the control group before the test, placed in a constant temperature and humidity chamber at 20°C and relative humidity of 65% for two weeks. The specimens were put in the holes and filled. In order to reduce the test errors of JC and RP, the two test pieces were buried in adjacent positions according to the same numbers. The test period was from March 2019 to December 2020. The pH of the soil on the test site was measured in December of the same year. The sample soil and DI water were employed to prepare 1:5 (v/v) solution, kept still for 8 h, filtered through circular analytical paper, and then the filtrate was measured by pen type pH meter (Suntex TS–1). A total of six specimens of JC and RP were sampled at intervals of 3–6 months, and the soil and residue were brushed away from the specimen surface. The specimens were placed in the oven at 103±2°C for 24 h, the absolute–dried weight was measured, and the weight loss rate was calculated according to the aforementioned decay resistance test equation.

*Determination of durability in outdoor corridors*

The JC and RP LVLs were placed in the corridor, ventilated and free from solarization. The test pieces were placed 45 cm above the ground. The air circulated between layers of stacks for 36 weeks. The temperature and humidity of Chiayi Taiwan provided by the Central Weather Bureau were used as climate reference data for the entire test. The specimen size was 50×50 mm. After staying in the environment at 20°C with 65% of RH for two weeks, the specimens were taken out of the outdoor corridor after 0, 4, 8, 12, 24, and 36 weeks. Each specimen was weighed ($W_f$) before placement. In total, six specimens were taken out after the aforementioned conditions for two weeks. The weight ($W_b$) was measured, and then the weight loss rate was calculated by equation (WL, %) =[ ($W_f$–$W_b$) /$W_f$] ×100.

*Statistical analysis*

Statistical analysis was performed by t–test using Statistical Product and Service Solutions. Differences were considered statistically significant when $\rho$ <0.05.

## RESULTS AND DISCUSSION

### Fungi resistance

The growth rates of two species with various specimens on the surface of JC and RP veneers increased obviously from Day 3 to Day 4. Notably, the same uptrend remained till Day 7, where the JC veneer had a lower fungal growth rate, meaning it had better fungi resistance than RP (**Table 1**). Morita *et al*. (1997) evaluate the effects of JC extracts on inhibiting fungal growth and realize a good antimicrobial activity for fungi. Cheng and Chang (2002) and Cheng *et al*. (2005) also indicate that the JC essential oil has an antifungal activity.

The parallel and perpendicular directions of both LVL specimens had the same *Aspergillus flavus* growth result till Day 7. However, the *Aspergillus flavus* growth rate of the parallel direction JC LVL on Day 5 and Day 6 was lower than that of the RP LVL by 10–15%, and both of species had similar *Aspergillus niger* growth trends. The results of *Aspergillus flavus*, *Aspergillus niger*, and the airborne fungi particles were compared. It was observed that the *Aspergillus flavus* had the highest growth rate among the three groups up to Day 7. Viitanen (1995) indicated that the growth of fungi on the wood surface depended mainly on the ambient relative humidity, temperature, light, application time, the existence of other microbes, and the wood surface nutrient content. The RH, temperature, and illumination factors were controlled in this test, which might be related to the existence of other microbes and the wood surface nutrient content. There was a slight difference between the growth rates of parallel and perpendicular directions of both LVL specimens. The perpendicular direction JC LVL had a higher *Aspergillus niger* growth rate than the RP, and the other results showed that the JC specimens had better fungi resistance than the RP.

To sum up, the species on the veneer of both JC and RP specimens had a lower growth rate, followed by the parallel and the perpendicular directions of both LVLs. Moreover, the perpendicular directions of both LVLs had the worst fungi resistance. The coniferous species absorbed liquid through the tracheid in a longitudinal direction, tracheid pit in a tangential direction, through wood ray parenchyma, wood ray tracheid, and resin channel in a radial direction (Erickson, 1938). Besides, the adhesives on different test surfaces of LVL had different influence, and the added starch might permeate in the tracheid to influence fungal growth.

### Decay resistance

The weight loss rate of JC veneer induced by brown–rot fungi (*Laetiporus silphureus*) was lower than that of the RP (**Fig. 1**) because the JC essential oil had compounds' resistant to wood–decaying fungi (Cheng, 2006). The JC LVL after being mass–produced from JC veneer was still with decay resistance, or probably under the effect of adhesives, the weight loss rates of the parallel and perpendicular direction of JC and RP LVLs were insignificantly. Meanwhile, the weight loss rates of the parallel and perpendicular direction of RP

**Table 1.** Fungi resistances of fungi inoculated on Japanese cedar and radiate pine with various types of specimens

| Specimen | Fungi | Species [2] | Growth rate (%) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 |
| Veneer | *Aspergillus niger* | JC | + [3] | + | + | ++ | +++ | +++ | ++++ |
| | | RP | + | + | ++ | +++ | ++++ | ++++ | +++++ |
| | *Aspergillus flavus* | JC | − | − | − | + | ++ | +++ | +++++ |
| | | RP | − | − | + | ++ | +++ | +++++ | +++++ |
| | Airborne fungi particles | JC | + | + | + | + | ++ | +++ | +++ |
| | | RP | + | + | ++ | +++ | ++++ | ++++ | +++++ |
| Parallel direction of LVL [1] | *Aspergillus niger* | JC | + | + | ++ | +++ | ++++ | ++++ | ++++ |
| | | RP | + | + | + | ++ | +++ | ++++ | +++++ |
| | *Aspergillus flavus* | JC | − | − | − | + | +++ | ++++ | +++++ |
| | | RP | − | − | − | + | +++ | +++++ | +++++ |
| | Airborne fungi particles | JC | + | + | + | + | ++ | ++ | ++ |
| | | RP | + | + | + | + | + | +++ | ++++ |
| Perpendicular direction of LVL | *Aspergillus niger* | JC | − | + | +++ | +++ | ++++ | +++++ | +++++ |
| | | RP | + | + | + | +++ | ++++ | +++++ | +++++ |
| | *Aspergillus flavus* | JC | − | − | − | + | ++ | ++++ | +++++ |
| | | RP | − | − | − | ++ | ++ | ++++ | +++++ |
| | Airborne fungi particles | JC | − | + | + | ++ | +++ | ++++ | +++++ |
| | | RP | + | + | + | ++ | +++ | ++++ | +++++ |

[1] LVL: Laminated veneer lumber
[2] JC: Japanese cedar (*Cryptomeria japonica*); RP: Radiate pine (*Pinus radiate*)
[3] Growth rate of fungi resistance: + sign represented the 20% growth rate range; +: 0–20%; ++: 20–40% and so on

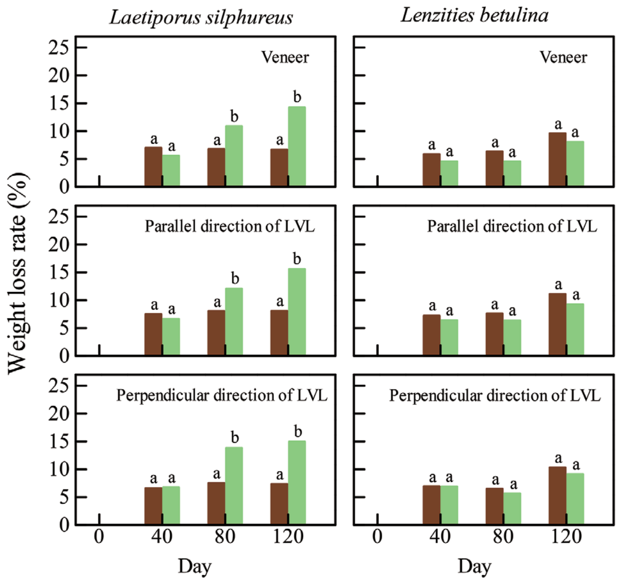


**Fig. 1.** Weight loss rate of different rot fungi on various types of specimens of Janpanese ceder and radiata pine.
Legends ■: Janpanese ceder (JC); ■: radiata pine (RP)
Note LVL: Laminated veneer lumber

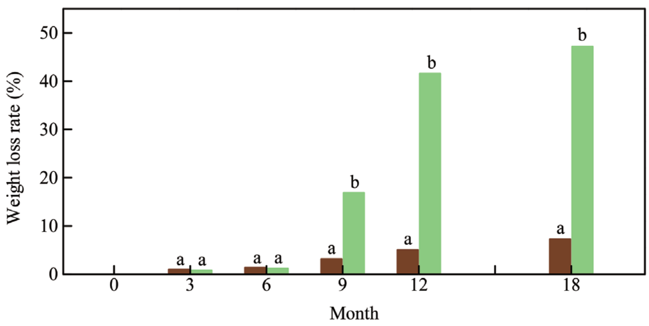


**Fig. 2.** Weight loss rate of residual cores after being buried in the field.
Legends ■: Japanese cedar (JC); ■: radiata pine (RP)

LVL increased significantly after 50 days, showing significant differences because the RP was free from decay resistance (Morita *et al.*, 1991 and 1997).

The weight loss rate of the JC veneer and the parallel and perpendicular direction of JC LVL inoculated with white–rot fungi (*Lenzities betulina*) was higher than that of the RP, there was no significant difference. In addition, the weight loss rate of the specimens of JC veneer rotted by brown–rot fungi and white–rot fungi for 120 days was a slightly lower than that of the JC LVL. Such a result may be explained by the LVL mass-produced reducing its compounds of veneer, which influenced the decay resistance (Nzokou *et al.*, 2005). Additionally, cellulose accounts for about 46.49% of the main chemical composition of JC, while hemicellulose accounts for about 12.61%, and lignin accounts for about 34.15% (Ku and Chen, 1986). As the brown–rot fungi mainly rot cellulose, and the white–rot fungi rot lignin (Hunt and Garratt, 1975), the weight loss rate of the specimen induced by brown–rot fungi may be a litter higher than that induced by white–rot fungi.

## Natural durability of field buried residual core

The average temperature throughout the test was 25.39°C, while the mean relative humidity (RH) was 74.74%. The average precipitation was 145.91 mm, the maximum precipitation was 631.50 mm, the minimum precipitation was 0 mm, and the average sunshine hour was 6.21 h/day. In the second period of taking out test specimens, the average air temperature was 26.71°C, the mean RH was about 76%, the average precipitation was 262.47 mm, and the average sunshine hour was 5.19 h/day. The weight loss rate of JC was 0.99%, while that of RP was 0.79%. However, there was no significant difference between them according to the t–tests (**Fig. 2**).

In the third period of taking out test specimens, the average temperature was 25.43°C, while the mean RH was about 73%. The average precipitation was 45.9 mm, and the average sunshine hour was 6.94 h/day. The soil pH was 7.52, where something like fungi adhering to the surface of the JC test specimen and biological deterioration of the RP test specimen could be observed. And, the weight loss rate of the RP test specimen after being buried for nine months was apparently lower than that of the JC, showing a significant difference between them according to the t–tests. When the test specimens were taken out for the fourth time, the soil pH was 7.78. Notably, the RP was severely influenced by biological deterioration, and its weight loss rate was apparently lower than that of the JC, indicating a significant difference.

Afterward, the weight loss rates of the JC taken out for the fifth time and sixth time were 5.02% and 7.26%, respectively. On the other hand, the weight loss rates of the RP were as high as 41.60% and 47.21%, respectively. There were significant differences between them. Because a highly humid environment is suitable for fungal growth, a high equilibrium moisture content in wood can accelerate decay of fungi (Kirk and Cowling, 1984; Haygreen and Bowyer, 1996). The JC and RP suffered more fungal damages in the initial stage of the test. Cheng *et al* (2005) indicated that the essential oil and methanol extracts of JC heartwood had a good inhibitory effect on wood–decaying fungi and termites since the heartwood essential oil contained compounds with good anti–termite activity.

The RP cell wall has a high rotten degree. Since the average sunshine hour per day extended after the rainy season, the biological damage was accelerated. The specimen was damaged by termites because the soft springwood is the favorite food of termites. Therefore, only the hard autumn wood remains. There is no surface loss observed on the JC specimen, which may be explained by the good anti–termite activity, making it insusceptible to biological damages (Cheng and Chang, 2002). Nzokou *et al.* (2005) indicate that the mixture of the veneer assortments with resistance to biological deterioration and without resistance to biological deterioration can effectively enhance the natural durability of LVL while the buried them in the field

## Durability of LVL in outdoor corridors

The entire test went through 36 weeks. The average

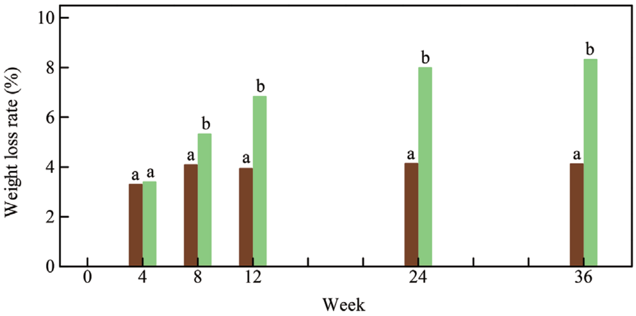


**Fig. 3.** Weight loss rate of durability of LVL in outdoor corridor.
Legends ■ : Japanese cedar (JC); ■ : radiata pine (RP)
Note LVL: Laminated veneer lumber

value of air temperature, RH, precipitation, maximum precipitation, and sunshine hour were 25.43°C, 74.08%, 96.26 mm, 287.30 mm, and 6.26 h/day, respectively. The 12 weeks before the test was summer, with an average air temperature of 30.18°C. The total precipitation was higher from Week 0 to Week 4. The weight loss rate of JC LVL after 36 weeks was 4.11%, while that of RP was 8.31%, showing significant differences between them in Week 8, Week 12, Week 24, and Week 36 (**Fig. 3**). The outdoor durability of wood is mainly influenced by temperature, RH, UV (sunlight), and rain (Hunt and Garratt, 1975).

Further, forming deterioration and the photooxidation reaction are formed after UV–irradiation so that the wood deteriorated, the texture is softened and embittered, and the mechanical properties are degraded. The chemical composition and physical characteristics of wood are changed in the deterioration and the wood surface even fades, deteriorates, and cracks (Evans *et al.*, 2000; Evans *et al.*, 2002; Heitner, 1993; Kuo and Hu, 1991; Chang *et al.*, 1982). Denes and Young (1999) and Kalnins and Feist (2002) also indicate that the rain plays an important effect on outdoor tests. When the wood deteriorates, the generated light–deteriorated substances can be removed by rain out. As a lot of rainwater washes the wood surface, it is likely to induce physical deterioration of the wood surface.

Additionally, while cellulose accounts for about 46.49% of the main chemical composition of JC (Ku and Chen, 1986), the cellulose content in the 20 years old RP is 41.48% (Berrocal *et al.*, 2004). Kim *et al.* (2016) indicates that although the lignin and hemicellulose are influenced by natural deterioration first, the cellulose is relatively complete. Therefore, the lower weight loss rate of JC LVL than that of RP may have resulted from the chemical compounds and cellulose content.

## CONCLUSION

The fungi resistance and decay resistance of veneer and two type of LVLs, and the natural durability of field-buried residual core were investigated. The LVL specimens mass-produced from JC and RP. Such experimentation was conducted to evaluate the difference between the JC and RP regarding their resistance to microbial deterioration. The JC veneer had a lower fungal growth rate than the RP, while the fungal growth rate of the parallel and perpendicular direction of JC LVL was slightly higher than that of the RP, but there was no significant difference between them. The weight loss rates of the JC veneer, and the parallel and perpendicular direction of JC LVL decayed naturally by brown–rot fungi for 120 days were lower than that of the RP. In terms of the three specimens rotted by white–rot fungi, although the RP was lower than the JC, there was insignificantly. The weight loss rates of the JC and RP after being buried in the wild for 18 months were 7.26 and 47.21%, respectively. The weight loss rate of JC LVL after the durability test in the outdoor corridor was lower than that of RP by almost two times. Therefore, the JC LVL had better resistance to microbial deterioration and natural decay than the RP LVL, making the former more feasible to be used as the outdoor material. It can be used as a consult for mass-produced JC into LVL in the future.

## AUTHOR CONTRIBUTION

Tsang–Chyi SHIAH wrote this paper and provided the equipment. Li–Sheng LIN performed the course/experiments and evaluated data with the statistical analysis. Han Chien LIN designed the study and guided the experiments. Noboru FUJIMOTO supervised the work. The authors assisted in editing of the manuscript and approved the final version.

## ACKNOWLEDGEMENTS

The authors offer our sincere appreciation to the Chiayi Forest District Office, Forest Bureau, Council of Agriculture, Executive Yuan, Taiwan ROC through No. Ze107–51 for financial support. The authors are grateful to the undergraduate student at 2018 for assisting this research experiments.

## REFERENCES

Berrocal, A., J. Baeza, J. Rodríguez, M. Espinosa and J. Freer 2004 Effect of tree age on variation of Pinus radiata D. Don chemical composition. *Journal of the Chilean Chemical Society*, **49**(3): 251–256

Chang, S. T., D. N. S. Hon and W. C. Feist 1982 Photodegradation and photoprotection of wood surface. *Wood and Fiber Science*, **14**(2): 104–117

Cheng, S. S. and S. T. Chang 2002 Antitermitic activity of *Cryptomeria japonica* essential oil. *Quarterly Journal of Chinese Forestry*, **35**(2): 193–199

Cheng, S. S., H. Y. Lin and S. T. Chang 2005 Chemical composition and antifungal activity of essential oils from different tissues of Japanese cedar (*Cryptomeria japonica*). *J. Agric. Food Chem.*, **53**(3): 614–619

Cheng, S. S., H. T. Chang, H. J. Gu, C. Y. Ku and S. T. Chang 2006 Antifungal activity of essential oils and their constituents from black heartwood–type *Cryptomeria japonica*. *Quarterly Journal of Chinese Forestry*, **39**(4): 557–574

Cheng, S. S. 2006 *Analyses and identification of antifungal and insecticidal compounds from Cryptomeria japonica*. Institute of Forest Environment and Resources Science, National Taiwan University PhD thesis 204.

Denes, A. R. and R. A. Young 1999 Reduction of weathering degradation of wood through plasma–polymer coating. *Holzforschung*, **53**(6): 632–640

Erickson, H. D. 1938 The flow of liquids through radial resin canals. *Journal of Forestry*, **36**: 417–423

Evans, P. D., A. F. A. Wallis and N. L. Owen 2000 Weathering of chemically modified wood surfaces. *Wood Science and Technology*, **34**(2): 151–165

Evans, P. D., N. L. Owenb, S. Schmide and R. D. Webste 2002 Weathering and photostability of benzoylated wood. *Polym. Degrad. Stab.*, **76**: 291–303

Haygreen, J. G. and J. L. Bowyer 1996 *Forest products and wood science: an introduction* (No. Ed. 3). Iowa state university press. USA. pp. 155–175

Heitner, C. 1993 *Light–induced yellowing of wood–containing papers*. pp. 2–22. In C. Heitner and J. C. Scaiano eds. Photochemistry of Lignocellulosic Materials. American Chemistry Society. Washington D. C. p. 223

Hunt, G. M. and G. A. Garratt 1938 *Wood preservation*, New York & London, McGraw Hill Book Company, Inc. p. 457

Kamala, B. S., P. Kumar, R. V. Rao and S. N. Sharma 1999 Performance test of laminated veneer lumber (LVL) from rubber wood for different physical and mechanical properties. *Holz als Roh-und Werkstoff*, **57**(2): 114–116

Kalnins, M. A. and W. C. Feist 1993 Increase in wettability of wood with weathering. *Forest Products Journal*, **43**(2): 55

Kim, Y. S., K. H. Lee and J. S. Kim 2016 Weathering characteristics of bamboo (*Phyllostachys puberscence*) exposed to outdoors for one year. *Journal of Wood Science*, **62**(4): 332–338

Kirk, T. K. and E. B. Cowling 1984 *Biological decomposition of solid wood. The chemistry of solid wood*. American Chemical Society. Washington. D. C. 207. pp. 455–487

Ku, Y. U. and H. T. Chen 1986 Pulping of small diameter tree of *Cryptomeria japonica. Taiwan Forest Research Institute*, **462**: 1–8

Kuo, M. L. and N. Hu 1991 Ultrastructural changes of photodegradation of wood surface exposed to UV. *Holzforschung*, **45**(5): 347–353

Morita, S., M. Yatagai and T. Ohira 1991 Antimite and antifungi activities of the hexane extractives from yakusugi bogwood (in Japanese). *Mokuzai Gakkaishi*, **37**: 352–357

Morita, S. I., T. Hidaka, and M. Yatagai 1997 Antifungal components of the extractives of Yakusugi. *Mokuzai Hozon* (Wood Protection), **23**(2): 61–69

Nzokou, P., J. Zyskowski, S. Boury and D. P. Kamdem 2005 Natural decay resistance of LVL made of veneers from durable and non–durable wood species. *Holz als Roh-und Werkstoff*, **63**(3): 173–178

Ozarska, B. 1993 A review of the utilization of hardwoods for LVL. *Wood Science and Technology*, **33**: 341–351

Robbins, E. H. 1989 *Laminated veneer lumber (LVL)*. U.S. Patent No. 4844763

Sogabe, A., K. Kinjo, F. Abe, T. Yamauchi and S. Yaga 2000 Termiticidal substances from the heartwood of *Cryptomeria japonica* D. Don. (in Japanese) *Mokuzai Gakkaishi*, **46**: 124–131

Viitanen, H. 1995 *Models of the critical time of humidity and temperature conditions for the development of would fungi in pine and spruce sapwood*. The International Research Group on Wood Protection, Document No.IRG/WP 96–20066

Wang, B. J. and C. Dai 2005 Hot–pressing stress graded aspen veneer for laminated veneer lumber (LVL). *Holzforschung*, **59**(1): 10–17

Forest Bureau 1995 The third forest resource survey report. Forest Bureau, Council of Agriculture, Executive Yuan. https://www.forest.gov.tw/0000052?iPage=2, 07072021

Forest Bureau 2016 The fourth forest resource survey report. Forest Bureau, Council of Agriculture, Executive Yuan. https://www.forest.gov.tw/00023930, 07072021