World Conference on Timber Engineering Oslo 2023

STUDY ON ENVIRONMENT DECOMPOSITION AND STRENGTH OF CLT WHEN TEMPORARILY USED ON CIVIL ENGINEERING

Naoya Iizawa[1], Kei-ichi Imamoto[2], Chizuru Kiyohara[3], Hideyuki Nasu[4], Satoshi Onishi[5],

ABSTRACT: This study examines the civil engineering use of CLTs; if the civil engineering use of CLTs is promoted, the supply of domestically produced CLTs will increase and stabilize, and the price of CLTs will decrease. The purpose of this study is to verify the conditions of use and decomposition in a civil engineering environment. As initial tests, visual observation, 3-point bending tests, and compression tests were conducted to verify the rate of strength degradation and degradation conditions for each elapsed month. As a result, since there was a large strength fluctuation at the same moisture content in terms of the embedded yield strength, an additional verification using small specimens was conducted. The results suggest that the strength reduction in the buried specimens was due to the absorption of water during the burial period, as well as minor but significant biodeterioration.

KEYWORDS: Timber material, CLT, Civil engineering use, Degradation, Strength reduction rate, Moisture content

1 INTRODUCTION

In recent years, against the backdrop of global environmental issues, Cross Laminated Timber (hereafter, CLT) is expected to become a wood-based building material that can curb CO2 emissions and effectively utilize forest resources. In Japan, however, the post-war period saw a sharp increase in demand for lumber, but a significant shortage in the supply of domestic lumber caused the price of domestic lumber to skyrocket, leading to a massive supply of imported lumber. As a result, the demand for imported lumber increased dramatically, and the demand for high-priced domestic lumber decreased dramatically. In addition, many trees were planted before the supply of imported timber, but the dramatic increase in demand for imported timber has resulted in many the planted trees being left unattended. Furthermore, Japan has many steep mountains that prevent large heavy machinery from entering the mountains, making it difficult to secure a stable distribution volume of lumber, and the complicated transportation system has led to high intermediate costs, which have caused lumber prices to skyrocket. Therefore, CLT is currently used only for low to mid-rise buildings and subsidized projects.

Therefore, we aim to expand the use of CLTs by making them more versatile. One idea is to apply CLTs to civil engineering materials, where the amount of used is small compared to the economic scale and there is room to expand its use. To increase the demand for timber and to utilize forest resources, civil engineering use of timber is already in progress, such as the use of wooden dams and ground improvement using wooden piles. When CLTs are used for this purpose, they can be substituted for the steel plates used to prevent the ground from being dented by the weight of large heavy machinery at construction sites. Usually, steel plates are collected after temporary construction and used again, but this is very disadvantageous in terms of transportation because they are extremely heavy and dangerous to work with. In addition, some people bury it without collecting them after construction is completed, but this is a major burden on the environment. Replacing these materials with CLTs will greatly reduce the weight, thus improving safety during transportation. In addition, since timber can be returned to the soil, even if it is not recovered and buried, it will lead to a reduction in the environmental burden. If the civil engineering use of CLTs is promoted, the supply of domestic lumber will increase and stabilize, which will contribute to a reduction in the price of domestic lumber. However, it is necessary to clarify the conditions under which CLTs can be used and the conditions and length of time required for their return to the natural world, and whether they can be buried and decompose naturally.

Therefore, this study verifies the conditions of use, conditions of return to nature, and the number of years of use of CLTs, and proposes a deterioration prediction equation that serves as an index for the number of years of use. As an initial verification, the strength degradation rate and degradation condition of CLT were verified for each elapsed number of months.

[1] Naoya Iizawa, Graduate Student, Tokyo University of Science, Japan, naoya.iizawa@gmail.com
[2] Kei-ichi Imamoto, PhD. in Eng., Tokyo University of Science, Japan, imamoto@rs.tus.ac.jp
[3] Chizuru Kiyohara, PhD. in Eng., Tokyo University of Science, Japan, ckiyo@rs.tus.ac.jp
[4] Hideyuki Nasu, PhD. in Eng., Nippon Institute of Technology, Japan, hideyuki.nasu@nit.ac.jp
[5] Satoshi Onishi, M. in Eng., Nippon Institute of Technology, Japan, onishi.satoshi@nit.ac.jp

https://doi.org/10.52202/069179-0114

2 SUMMARY OF EXPERIMENT

2.1 STRENGTH TEST

A summary of the specimens is shown in Table 1. The effects on strength and degradation were tested with and without adhesive bonding at the width-bonding area. The effects of different gaps in the width joints on degradation were also examined (Figure 1). In addition, the effects of different fiber orientations on strength and degradation were also verified. For some of the specimens, the difference in deterioration was compared between when the specimens were buried in the soil and when they were left outdoors.

2.2 VISUAL OBSERVATION

The deterioration of the specimens was visually observed, and image analysis was conducted to determine the area ratio of the deteriorated portions on the specimen surface.

Table 1: *List of experimental specimens*

Specimen name	Overview
Japan Standard	Bonding the width-bonded sections
European Standard	No bonding the width-bonded sections
Gap 2.5 mm	2.5 mm gap and bonding at each width joint (Figure 1)
Gap 5.0 mm	5.0 mm gap and bonding at each width joint
Laminated timber	The lamina fibers are aligned, laminated and glued together.

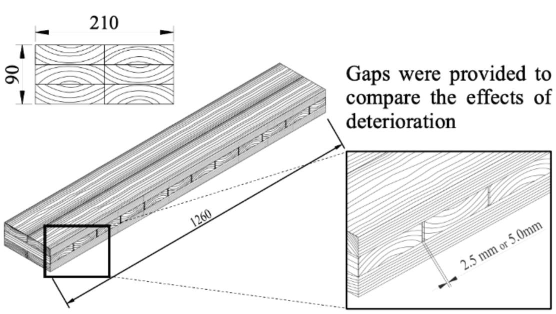


Figure 2: *Gap Specification Diagram*

2.3 EXPERIMENTAL PROCEDURE

2.3.1 BENDING TEST

Three-point bending tests were performed on a 2000 kN universal testing machine (Figure 2). The specimen was a 3-ply, 3-layer, 3-ply CLT of 1260×210×90 mm. After measuring the yield load and initial stiffness, the rate of strength loss was calculated for each elapsed month, and the strength loss and its factors were compared and discussed.

2.3.2 EMBEDDED COMPRESSION TEST

Tests were conducted using a 2000 kN universal testing machine (Figure 3). The specimen was cut out from the part with the least damage after the three-point bending test. The specimen was 210 x 210 x 90 mm in size, and a 100 x 100 mm loading plate was placed in the center of the end face. The test was conducted by loading the specimens until the flexural displacement exceeded 20 mm, measuring the load and flexural stiffness, and then calculating the strength degradation rate for each elapsed month to compare and discuss the strength degradation and its factors.

2.4 MOISTURE CONTENT MEASUREMENT

Moisture content was measured to verify the relationship between strength and moisture content. A high-frequency capacitance moisture content meter (HM-520) was used to measure the moisture content of the specimens.

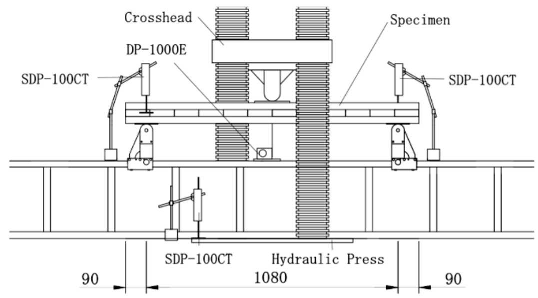


Figure2: *2000kN Universal Testing Machine and Specimen Installation Diagram.*

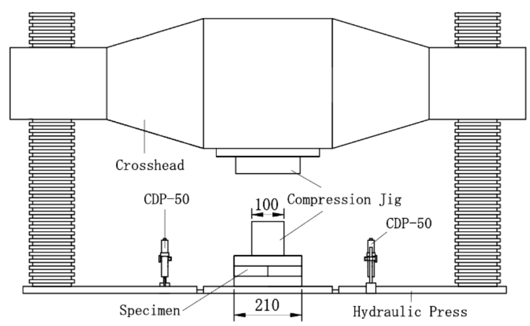
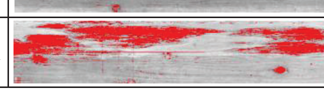


Figure3: *2000kN Universal Testing Machine and Specimen Installation Diagram.*

Table 2: *Image Analysis Result*

Lapsed month	Analysis image	Deterioration rate (%)
2month		0
4month		2.1
6month		4.8
8month		18.0

https://doi.org/10.52202/069179-0114

3 TEST RESULTS AND DISCUSSION

3.1 VISUAL OBSEVATION

The results of image analysis are shown in Table 2, which shows that the surface of the first layer of the specimen showed slight discoloration and insect bite marks starting from the fourth month. 2.1% of the specimen was discolored at the fourth month and 4.8% at the sixth month, which is a very small percentage of degradation, but it was confirmed that the longer the specimen was buried, the more the discolored areas increased. Regarding the deterioration factors, the sapwood, which is lighter in color, showed more damage, while the core timber, which is darker in color, showed less damage. The sapwood has low decay resistance, whereas the core timber has high decay resistance, and the fact that the damage looks like insect bites suggests that the cause of deterioration may be biodeterioration.

3.2 BENDING TEST RESULTS

Test results are shown in Table 3. Compared to CLT, the yield bending strength and bending stiffness of the glued laminated timber were greater. The laminated lumber is laminated in the parallel fiber direction, so all three layers exhibit performance when bending occurs, whereas the CLT is laminated in the transverse fiber direction, so the first and third layers in the fiber direction exhibit performance in bending, but the second layer in the transverse fiber direction has less resistance to bending. In fact, the section modulus for each fiber direction was calculated, and the section modulus of the second layer, which is transverse to the fiber direction, was about one-ninth that of the first and third layers, which are in the fiber direction. This characteristic is also manifested in the fracture properties: the CLT has low resistance to bending in the second layer, since the timber in the second layer often cracks (Figure 4). But no significant difference in bending stiffness of CLT was observed between the different specimen types.

Figure 5 shows the rate of decrease in yield bending strength. All the specimens showed a large decrease in the second month, but the rate of decrease fluctuated afterwards repeatedly since then. Although there was some variation, the rate of decrease in strength of the glued laminated timber was smaller than that of the CLT. Within the scope of this test, there was no clear difference in the effect of securing gaps as a route of entry for rotting fungi and termites, or of the presence or absence of gluing of the width-bonding. It was also confirmed that the strength loss of the specimens exposed outdoors was smaller than that of the specimens buried in the soil.

The specimens were removed from the soil and dried indoors for 5 days before bending strength tests were conducted. Therefore, the moisture content of the specimens at the time of the flexural strength test was different. Figure 6 shows the relationship between the moisture content at the time of measurement and yield bending strength. It was confirmed that the moisture content increased to 30% after 2 months of burial. The strength decreased significantly with moisture content up

Table 3: *Bending Test Results*

Lapsed month	Yield stress (kN)	Strength reducation rate (-)	Yield stress (kN)	Strength reducation rate (-)
	Japan Standard (Buried)		Japan Standard (Exosed)	
0	33.05		33.05	
2	13.54	0.60	23.76	0.28
4	22.18	-0.64	29.25	-0.23
6	17.01	0.23	16.52	0.44
8	19.84	-0.17	26.38	-0.60
	European Standard		Gap 2.5 mm	
0	28.55		24.79	
2	13.89	0.55	15.35	0.32
4	15.37	-0.11	16.32	0.15
6	13.02	0.16	15.62	0.04
8	20.77	0.60	12.06	0.23
	Gap 5.0 mm		Laminated timber	
0	26.20		57.16	
2	17.73	0.32	39.97	0.30
4	15.06	0.15	42.56	-0.06
6	16.74	-0.11	40.53	0.04
8	18.99	-0.13	38.77	0.04

Figure 4: *Fracture Properties*

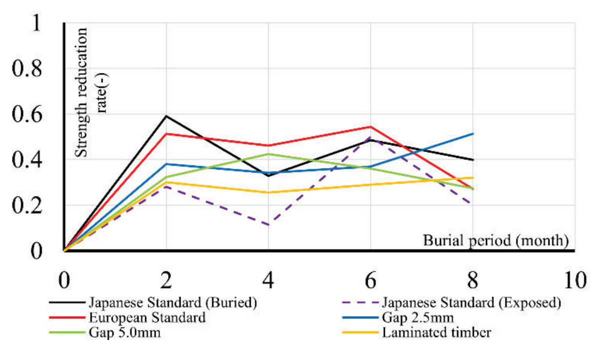


Figure 5: *Yield Bending Strength Reduction Rate*

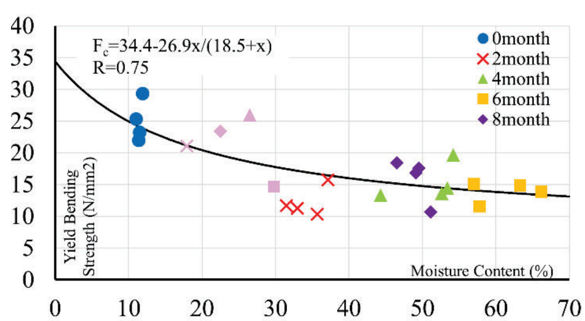


Figure 6: *Yield Bending Strength - Moisture Content*

https://doi.org/10.52202/069179-0114

to the fiber saturation point of 30%, but the decrease in strength with increasing moisture content tended to be small for moisture contents above 40%. The coefficient of variation of yield strength is 17% according to Sasaki et al. [4], and the image analysis results in Table 2 suggest that the factor of yield strength reduction shown in Figure 6 is due to the absorption of moisture during the burial period, and the influence of biological deterioration such as decay fungi and insect damage could not be confirmed within the scope of this test.

3.3 RESULTS OF THE COMPRESSIVE TEST

The test results are shown in Tables 4. Unlike the bending strength properties, there was no significant difference between the glued laminated timber and CLT specimens in terms of the embedded stiffness. The percentage of decrease in yield strength under shear (Figure 7) shows that the percentage of decrease in yield strength under shear was larger than that of yield bending strength for all the specimens. Therefore, in outdoor use of CLTs, it is necessary to consider the decrease in the embedded strength during the service period.

In terms of the embedded yield strength, the rate of strength reduction tends to be greater for glued laminated timber than for CLT. The parallel fiber lamination of the glued-laminated timber may have weakened its resistance to compression. A comparison of fracture properties (Figure 8) shows that timber cracking was concentrated in the first layer of CLT, whereas cracking also occurred in the second and third layers of glued-laminated timber. In addition, in the glued-laminated timber, the timber in the upper layer was embedded into the timber in the lower layer, which is thought to be one of the reasons for the reduction in bearing capacity that is assumed to occur when the timbers are stacked in the parallel direction to the fibers.

Next, Figure 9 shows the relationship between moisture content at the time of the strength test and the yield strength of the specimens with a 2.5 mm gap. As with the yield bending strength, the embedded yield strength decreased significantly with decreasing moisture content up to 30%, the fiber saturation point, and the rate of change in strength with increasing moisture content was small when the moisture content was 45% or higher.

The coefficient of variation of the embedded yield strength is 12% according to Ido et al. [5], and the variation of the embedded yield strength in this test is large for the same moisture content. Therefore, in the next section, the effect of moisture content on the embedded yield strength of undamaged solid timber and CLT specimens will be examined.

4 RELATIONSHIP BETWEEN EMBEDDED YIELD STRENGTH AND MOISTURE CONTENT

4.1 VERIFICATION USING SMALL SPECIMENS

The change in compressive strength under penetration

Table 4: *Compression Test Results*

Lapsed month	Yield stress (kN)	Strength reducation rate (-)	Yield stress (kN)	Strength reducation rate (-)
	Japan Standard (Buried)		Japan Standard (Exposed)	
0	45.36		45.36	
2	21.16	0.54	19.32	0.58
4	10.62	0.50	7.74	0.60
6	9.90	0.07	31.42	-3.06
8	13.76	0.39	17.84	0.43
	European Sandard		Gap 2.5 mm	
0	31.58		35.66	
2	32.82	-0.07	15.66	0.54
4	7.72	0.76	9.46	0.40
6	22.27	-1.88	13.65	-0.44
8	16.76	0.25	8.74	0.36
	Gap 5.0 mm		Laminated timber	
0	29.94		40.04	
2	14.32	0.52	6.88	0.83
4	7.72	0.46	6.76	0.02
6	17.43	-1.26	14.04	-1.07
8	16.90	0.03	8.67	0.38

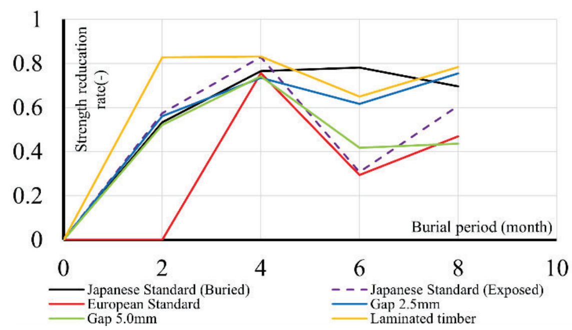


Figure 7: *Embedded Yield Strength Reduction rate*

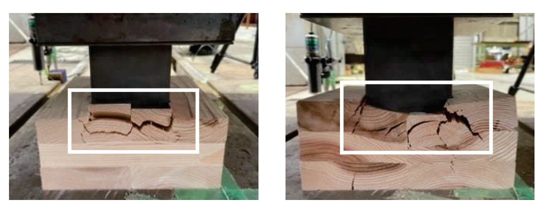


Figure 8: *Fracture Properties*

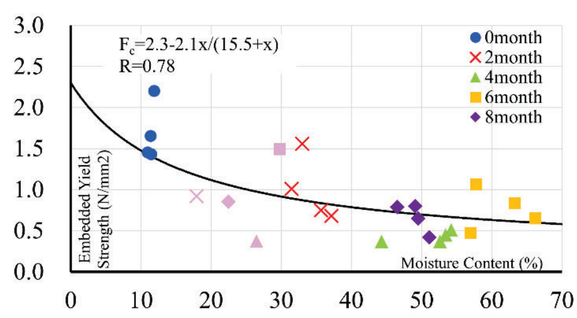


Figure 9: *Embedded Yield Strength - Moisture Content*

https://doi.org/10.52202/069179-0114

was verified using solid Japanese cedar specimens with different moisture contents. All specimens were dried in a constant-temperature room at 40°C and allowed to absorb water naturally to keep the moisture content in the range of 0% to 70%. Since it takes time for the specimens with high moisture content to absorb water, the specimens were vacuumed for 1 hour, allowed to stand for 1 hour after water injection, and then recompressed for 1 day, as shown in Figure 10. The test was conducted using a 50 kN table-top precision universal testing machine with a 10×10mm loading plate. The test was displacement-controlled, and force was applied at a rate of 2 mm/min. The test was terminated when the force reached 5% of the edge length. The embedded yield strength was calculated, and the coefficient of variation was calculated from the mean value and standard deviation to evaluate the variation. The results are shown in Table 5 and Figure 11. While the embedded yield strength decreases significantly as the mass water content changes up to the fiber saturation point of 30%, the strength decrease tends to be smaller when the mass water content is 40% or higher. According to Sawada [6], the coefficient of variation of the embedded yield strength of solid SUGI lumber is estimated to be around 20% to 30%, and in this test, the coefficient of variation of the embedded yield strength was 5 to 20%, which is within the range of variation. Although there was some variation in vacuum water absorption, many of the specimens were within the variation range, suggesting that they could be evaluated in the same manner as the other specimens.
Using these test results as a baseline, similar tests were conducted on smaller CLT specimens in the next section to verify the variation of the yield strength due to the change in moisture content.

4.2 VERIFICATION USING CLT SMALL SPECIMENS

The effect of moisture content on the yield strength of CLT is verified by using a small CLT specimen. The test specimens were 100 mm square pieces of 3-ply CLT after the flexural strength test used in Section 3.2. The test specimens were prepared in the same way as the small specimens, with moisture content ranging from 0 to 70%, and vacuum water absorption was performed for moisture contents of 50% to 70% based on the results of the small specimens. The test method was the same as for the small specimens, and the size of the loading plate was 40 × 40 mm. As with the small specimens, the yielding strength was calculated, and the coefficient of variation was calculated from the mean and standard deviation of the yielding strength to evaluate the variation.
Table 6 and Figure 12 shows the test results. Like the results of the small specimen described above, the yield strength of the specimen decreased significantly as the moisture content increased up to 30%, the fiber saturation point, but the decrease in strength tended to be small when the moisture content increased above 40%. Only one specimen had high embedded yield strength in the moisture content range of 15-30% and 30-50%, but this is due to the presence of knots on the compression surface.

Table 5: *Small Specimens Results*

Parameter		Embedded Yield Strength (N/mm²)	Moisture Content (%)
0%	Average	1.68	0.50
	Standard Deviations	0.32	0.71
	Variation Coefficient (-)	0.19	1.44
15~30%	Average	0.91	22.71
	Standard Deviations	0.16	3.77
	Variation Coefficient (-)	0.18	0.17
30~50%	Average	0.75	37.92
	Standard Deviations	0.16	4.43
	Variation Coefficient (-)	0.21	0.12
50~70% (Vacuum Suction)	Average	0.76	68.36
	Standard Deviations	0.30	0.95
	Variation Coefficient (-)	0.40	0.01
50~70% (Natural Suction)	Average	0..74	66.39
	Standard Deviations	0.06	0.81
	Variation Coefficient (-)	0.09	0.01

Figure 10: *Vacuum Suction*

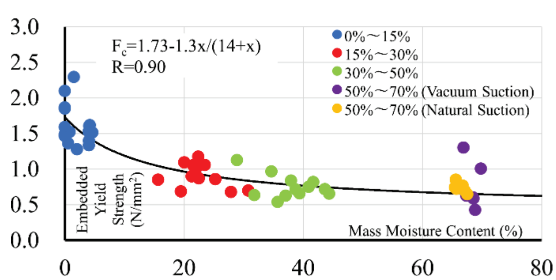


Figure 11: *Embedded Yield Strength - Moisture Content*

The specimens with vacuum-absorbed water also showed some variation. One of the reasons for this may be that CLTs are subjected to a greater load than solid timber because the expansion of CLTs is inhibited by the adhesive, which is a factor in the expansion of timber as a result of water absorption. The adhesive used was a water-based polymer isocyanate adhesive, but the effect of the adhesive needs to be further investigated.

Next, a comparison was made with the small specimens and the strength tests in Section 3, considering the dimensions of the specimens and the pressurized plate, and the yield strength of the specimens was calculated using the following equation (1).

$$Fc = Fy / (b \cdot l) \quad (1)$$

where Fc=Caving-in yield strength (N/mm^2), Fy=Yield load (N), b=Specimen width (mm), l=Length of pressurized plate (mm).
Compared to the small specimen, the yielding strength of this test was slightly higher than that of the small specimen. This is due to the orthogonally stacked CLT fibers. The relationship between the embedded strength and the moisture content in the soil test (Figure 13) is compared. Since the slopes of the approximate formulas are similar before the fiber saturation point, the strength reduction of the buried specimens is due to the absorption of water during the burial period. On the other hand, after the fiber saturation point, the strength difference is larger, suggesting that biodeterioration, although small, has affected the strength of the buried specimens. However, due to the small number of specimens, the approximate formula needs to be further studied.

5 CONCLUSIONS

The findings of this study are as follows.
1) Although differences in strength and stiffness were observed between laminated timber and CLT, no differences in specifications between CLTs were identified at this time.
2) Visual observation suggested the possibility of biodeterioration, but no effect of biodeterioration on the strength of the specimens was observed within the scope of the strength tests in Section 3.
3) The results of the compressive test on small specimens of solid timber and CLT indicated that the strength loss of the buried specimens was due to the absorption of moisture during the burial period as well as to a small amount of biodeterioration

Table 6: *CLT Small Specimens Results*

Parameter		Embedded Yield Strength (N/mm^2)	Moisture Content (%)
0%	Average	2.48	0
	Standard Deviations	0.28	0
	Variation Coefficient (-)	0.11	0
15~30%	Average	1.40	29.20
	Standard Deviations	0.59	8.99
	Variation Coefficient (-)	0.42	0.31
30~50%	Average	1.48	33.28
	Standard Deviations	0.66	5.83
	Variation Coefficient (-)	0.45	0.18
50~70% (Vacuum Suction)	Average	1.12	67.11
	Standard Deviations	0.33	1.13
	Variation Coefficient (-)	0.30	0.02

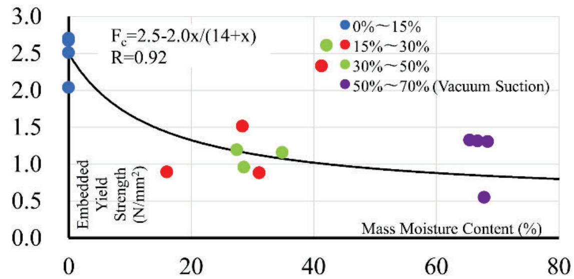


Figure 12: *Embedded Yield Strength - Moisture Content*

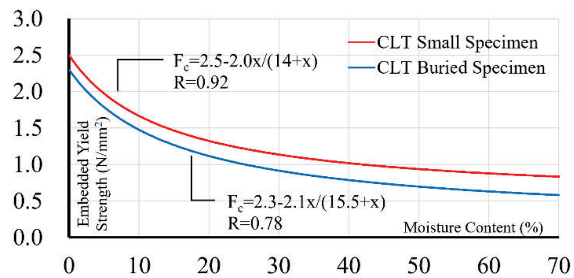


Figure 13: *Approximate Formula Comparisons*

REFERENCES

[1] N.Iizawa et al.; STUDY ON ENVIRONMENT DECOMPOSITION AND STRENGTH OF CLT WHEN TEMPORARILY USED ON CIVIL ENGINEERING, VERIFICATION OF STRENGTH REDUCTION RATE DEGRADATION FACTORS OF CLT. Collection of the Proceedings of the Annual Meeting of the AIJ 2022

[2] S.Onishi, H.Nasu ; STUDY FOR PRACTICAL USE OF NAIL-LAMINATED-TIMBER, EFFECTS OF GAPS AMONG THE LAMINAS DURING MANUFACTURING. Collection of the Proceedings of the Annual Meeting of the AIJ 2021.9

[3] M.Yamada, et al.; FUNDAMENTAL STUDY ON STRNGTHENING OF TERMITE INDUCED DETERIORATED TIMBER MEMBER WITH RESIN. NO.1 COMPRESSION TEST AND BENDING TEST. Collection of the Proceedings of the Annual Meeting of the AIJ 2021.

[4] T.Sasaki et al.; INFLUNCE OF LAYER COMPOSITION AND LAMINA GRADE ON IN-PLANE BENDING PERFORMANCE OF CLT. Collection of the Proceedings of the Annual Meeting of the AIJ 2015.

[5] H.Ido et al.; CAVING STRENGTH PERFORMANCE OF CROS LAMINATED TIMBER (CLT) MANUFACTURED USING JAPANESE CEDAR. Journal of the Japan Society of Wood Science and Technology Vol60, N0.1, p.16-22(2014)

[6] M.Sawada ; DEFORMATION BEHAVIOR OF WOOD. Materials Science Society of Japan, Vol.32, No.358, p.838-847(1983)

https://doi.org/10.52202/069179-0114