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A Study on Charring Depth of Cross-Laminated Timber(CLT) Walls under Non-Load Bearing Fire Test

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ABSTRACT: In this study, the char depth of cross-laminated timber (CLT) walls under non-load-bearing fire conditions was observed. The CLT wall specimens were composed of four specimens: two uncladded specimens and two cladded with dry fireproof boards. The results of the fire test of uncladded specimens showed that the charring depth increased linearly with fire duration, while the charring depth of the cladded specimens was reduced by approximately 30% compared to the uncladded specimen, and the charring effect was shown depending on the location of the joints. These results support the development of domestic fire design standards for CLT structures and may be helpful in material selection for future high-rise timber buildings.

KEYWORDS: Cross-laminated timber, CLT wall, Charring depth, Fire resistance, Fireproof covering

1 – INTRODUCTION

Wood-framed buildings can store four times more greenhouse gases than steel and reinforced concrete houses, and they are gaining attention as eco-friendly building materials with low carbon emissions because they use less energy during construction than other materials[1]. Among them, cross-laminated timber (CLT) is widely used as a wall and floor panel system for large-scale wood structures[2], [3], [4]. It is manufactured by laminating structural standard wood in odd layers at 90°, and has the advantages of strength and rigidity, low thermal conductivity, shortened construction period, and reduced construction cost[5]. CLT, an engineered wood, is classified as structural glulam along with glued-laminated timber(GLT), and is included in fire-resistant structures in Korea. Fire-resistant structures refer to structural members that have secured a certain level of fire resistance to prevent collapse due to damage to building structural members exposed to high temperatures in the event of a fire[6], [7]. Recently, various research and technology developments are being conducted to improve the structural stability and fire resistance of engineered wood including CLT[8], [9]. For example, methods are being attempted to improve fire resistance by applying fire-retardant treatment to the surface or combining it with non-combustible finishing materials such as gypsum board and inorganic panels[9], [10], [11]. These technologies go beyond simply extending the fire resistance time, and also play a major role in reducing harmful gas emissions in the event of a fire and securing time for people to escape[12]. When applying engineered wood as a fire-resistant structure for a building, the charring layer is calculated according to the required fire resistance time to derive the design section[9]. In other words, the engineered wood design section is a section that includes the charring layer and the sound section. In Europe, the United States, etc., the charring rate of the wood presented in the relevant standards or codes is used for design, and no separate fire resistance verification procedure is performed[13], [14]. It is technically recognized that the charring layer that occurs as a result of the thermal decomposition of wood exposed to high temperatures secures the fire resistance of the member. Although engineered wood is also used as a fire-resistant structure in Korea, in order to be used as a fire-resistant structure of a building, a performance test is performed to confirm the fire resistance and use it[6], [7]. Therefore, CLT or GLT are currently recognized by measuring the charring depth after a fire resistance test[15], [16], and engineered wood recognized as a fire-resistant structure is designed considering the recognized charring depth. Currently, in Korea, performance-based fire resistance design of up to 2 hours is possible based on the charring depth of the wood, so construction is freely possible up to 12 floors.

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This proves that wooden structures are sufficiently safe from fire depending on the design. However, in order to construct a super high-rise wooden structure of 12 stories or higher, a fire resistance performance verification of more than 2 hours and domestic fire resistance structural standards are required[6], [7].

2 – BACKGROUND

When wood is heated at room temperature, most of the moisture evaporates at about 100°C. When heated above 100°C, molecular level decomposition occurs, and wood gradually begins to pyrolyze between 100 and 200°C. When the temperature is above 200°C, the pyrolysis process becomes faster, and pyrolysis accelerates at 260 to 350°C. The generation of volatile gases, which are important pyrolysis products above 300°C, continues to increase. The charring layer generates combustible gases such as CO, CH_4, C_2H_4, H_2, organic acids, and aldehydes and non-combustible gases such as CO2 and H2O when wood pyrolyzes, leaving behind carbon (C) later[6], [17], [18]. When the temperature exceeds 200°C, the carbon layer becomes considerably black and is formed. When volatile gases are released and heated with oxygen, these gases are ignited by an ignition source such as a flame, and the temperature increases further. Above about 270° C, the heat generation rate becomes greater than the heat required for gas generation, and the fire does not go out. The charring layer remaining after the volatile gas escapes during the thermal decomposition process of wood increases in thickness over time, which tends to reduce the charring rate. Due to such thermal decomposition and the creation of charring layers, wooden structural members have sufficient fire resistance[18], [19].

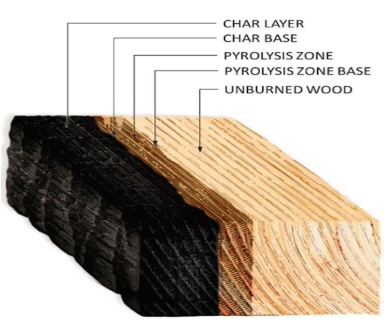

Figure 1. Degradation zone in a section of burnt wood.[18], [19].

3 – PROJECT DESCRIPTION

In order to apply engineered wood (glued laminated timber, cross-laminated timber) made of domestic wood as the main structural member in high-rise timber buildings, the fire resistance performance characteristics of domestic timber were analyzed to develop a standard fire resistance structure. It also aims to develop a domestic fire-resistant structure for glued laminated timber (beams, columns), cross-laminated timber (walls, floors) made of domestic wood, and cross-laminated timber (floor and wall members) using a dry fire-resistant covering method.

4 – EXPERIMENTAL SETUP

4.1 Specimens

This fire resistance test was conducted to verify the fire resistance of the domestically produced CLT wall over time and the cladding performance of fireproof gypsum board, and to compare the charring properties. The fire resistance test was conducted on 1-hour uncladded test specimens (CLTW-N-1h), 2-hour uncladded test specimens (CLTW-N-2h), and 2-hour fireproof gypsum board test specimens (CLTW-FP-2h). In order to confirm the effect of the joint location of the base and finish surfaces, the test specimens of 2-hour fireproof gypsum board classified into test specimens with matching base and finish joints (CLTW-FP-2h-1) and test specimens with mismatched base and finish joints (CLTW-FP-2h-2), and each test was conducted.

Uncladded specimens (CLTW-N-1h, CLTW-N-2h) were manufactured using only CLT members (210 mm) made from Korean larch. On the other hand, the 2-hour fireproof gypsum board specimen (CLTW-FP-2h) consisted of finished gypsum board (19 mm) - base gypsum board (19 mm) - studs, runners, and glass wool insulation (50 mm) - CLT (90 mm). The dry fire-resistant board cladding was selected as a fire-resistant gypsum board, and Radiata pine was applied for the studs and runners to fix the fireproof gypsum board to reflect the characteristics of the wood structure. The density of the glass wool insulation was 24K. The base surface, finished surface, and joint configurations of the CLTW-FP-2h-1 and CLTW-FP-2h-2 specimens are as shown in Figure 2 below, and an overview of the entire specimen is as shown in Table 1.

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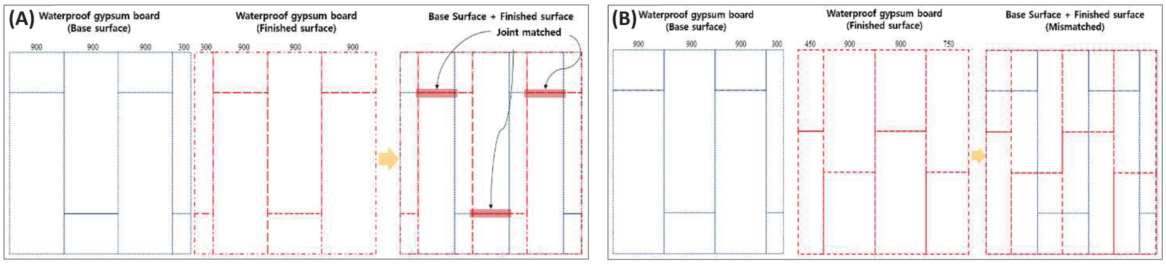

Figure 2. Joint occurrence according to the placement of fireproof gypsum board; (A) CLTW-FP-2h-1, (B) CLTW-FP-2h-2.

Table 1. Fire test conditions of specimens

Species	Name	Size (W×H×T, mm)	Time (min)
Korean Larch	CLTW-N-1h	3,000×3,000×210	60
	CLTW-N-2h	3,000×3,000×210	120
	CLTW-FP-2h-1	3,000×3,000×180	120
	CLTW-FP-2h-2	3,000×3,000×180	120

**CLTW : Cross-Laminated Wall, N : No cladding, FP : Fireproof board*

Figure 3. A specimen of CLT wall before fire test.

4.2 Fire resistance test

The fire resistance test of the CLT wall panel is conducted by heating one side of the specimen surface, and the test specimen is installed in a fixing frame and the fire resistance test is performed in a vertical furnace. Burners are arranged in a 4x4 arrangement to supply uniform heat to the heating surface of the test specimen, and are composed of intake and exhaust passages, air dampers, etc. The temperature inside the furnace was applied with a standard fire time-temperature curve(ISO 834-1 curve), and charring properties such as charring depth were observed. The charring depth of the CLT wall specimens was measured by collecting a circular core from the back of the specimen in the direction of the heating surface in the vertical direction of the wall cross-section. The measurement location was the point where charring occurred. Charring depth was calculated as the difference between the thickness of the specimen before the test, and the thickness at which no charring occurred.

5 – RESULTS

The average charring depth of the cross-laminated timber (CLT) wall specimens conducted under non-loaded conditions was measured as shown in Figure 4 and 5, and the average charring depth and average charring rate are shown in Table 2. The average charring depth and average charring rate of CLTW-N-1h and CLTW-N-2h were 52.6 mm, 0.87 mm/min and 112.3 mm and 0.67 mm/min, respectively. In uncladded specimens cases, the average charring depth and average charring rate increased steadily as the fire resistance time increased. When comparing the two specimens, the average charring rate actually increased as the fire resistance time increased, which is thought to be due to the insufficient formation of the charring layer or the failure of the charring layer to exert its covering effect due to the detachment of the charring layer[20], [21].

Table 2. Charring properties by test specimens

Specimen name	Time (min)	Charring Depth Avg. (mm)	Charring Rate Avg. (mm/min)
CLTW-N-1h	**60**	**52.6**	**0.87**
CLTW-N-2h	**120**	**112.3**	**0.94**
CLTW-FP-2h-1	**120**	**80.0**	**0.67**
CLTW-FP-2h-2	**120**	–	–

On the other hand, the average charring depth and charring rate of CLTW-FP-2h-1 cladding with dry fireproof gypsum board were 80.0 mm and 0.67 mm/sec, respectively. The specimen was installed with the finished gypsum board and the base gypsum board aligned. Because the joints of two fireproof gypsum board aligned, the vulnerable part, the joint, was exposed to fire, causing ignition and flames. This can be inferred from the charring shape and properties of the specimen.

Figure 4. Specimens of CLT wall after fire test; (A) uncladed CLT wall, (B) CLT wall cladded by fireproof gypsum board.

The CLTW-FP-2h-2 test specimen, which was manufactured by mismatching the joints of two fireproof gypsum boards, did not have charring depth. During the fire exposure time, two fire-resistant gypsum boards and insulation were exposed to the fire, but charring process of the CLT wall specimen did not occur, and the temperature inside the specimen did not exceed 200°C. In addition, the charring properties was confirmed during the test by the fact that ignition and flame did not occur at the joint location of the two gypsum boards[22].

Figure 5. Specimens for measuring charring depth.

When CLTW-N-2h was compared with CLTW-FP-2h-1, the average charring depth and average charring rate were reduced by approximately 29% simply by installing the fireproof gypsum boards, and charring process did not occur compared with CLTW-FP-2h-2. Through this, it was confirmed that the fire resistance performance was improved regardless of the joint location of the fireproof gypsum board, and that the fire resistance performance of the dry coating could be secured by adjusting the joint location.

Additionally, the unheated surface temperature change according to the specimen was measured as shown in Figure 6. Although the charring depth produced different results for each test specimen, the temperature of the unheated surface was confirmed to be similar for all four test specimens. This confirmed the heat-insulating effect of the CLT member regardless of the presence or absence of the fire-resistant gypsum board acting as a dry covering.

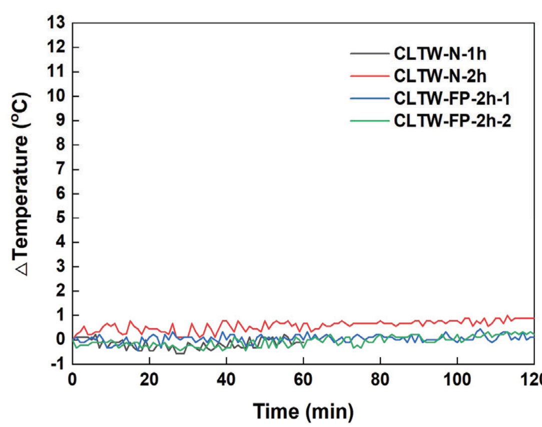

Figure 6. Changes in temperature of the unheated surface according to the specimens.

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6 – CONCLUSION

This study investigated the charring characteristics of cross-laminated timber (CLT) wall specimens under various fire exposure conditions. The experimental results demonstrated that in uncladded CLT wall specimens, the average charring depth and charring rate increased with longer fire resistance times. Notably, although longer fire exposure generally promotes charring layer formation, the increased charring rate observed in the CLTW-N-2h specimen suggests that ineffective charring layer development or detachment may impair its protective function.

On the other hand, specimens protected with dry-applied fireproof gypsum boards exhibited significantly improved fire resistance. In the case of CLTW-FP-2h-1, where gypsum board joints were aligned, charring was observed due to ignition at the vulnerable joint area, yet the average charring depth and rate were substantially lower compared to the uncladded specimen (CLTW-N-2h). Conversely, the CLTW-FP-2h-2 specimen, where the joints of the two gypsum boards were intentionally offset, showed no charring in the CLT layer, and the internal temperature remained below 200°C throughout the fire exposure. These results confirm that joint configuration plays a critical role in the fire performance of gypsum-clad CLT walls.

Overall, the application of fireproof gypsum boards—particularly with staggered joint placement—significantly enhances the fire resistance of CLT wall systems. These findings highlight the importance of appropriate cladding design in improving the fire safety of timber structures and provide practical guidance for optimizing joint configuration to maximize protection.

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