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Shear Performance of PUR Adhesive in Cross Laminating of Red Pine*[1]

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ABSTRACT

Cross laminated timber (CLT) has been an rising issue as a promising building material replacing steel-concrete in mid story rise construction. But, there was no specific standard for CLT because it had been developed in industrial section. Recently, new draft for requirements of CLT was proposed by EN which suggested to evaluate the performance of adhesive in CLT by the same method as glulam. But, it has been reported that shear performance of cross laminated timber is governed by rolling shear. Therefore, block shear tests were carried out to compare parallel to grain laminating and cross laminating using commercial one component PUR (Poly urethane resin). The result showed that the current glulam standard for evaluating bonding performance is not appropriate for CLT. Beacause shear strength of cross laminating decreased to 1/3 of parallel to grain laminating and this strength was representing shear performance of wood itself not the bond. However, cross laminating showed no significant effect on wood failure. Thus, wood failure can be used as a requirement of CLT bonding. Based on the results, cross laminating effect should be included when evaluating adhesive performance of CLT correctly and should be considered as an important factor.

Keywords : cross laminated timber, shear strength, wood failure, adhesive, PUR

1. INTRODUCTION

Demand on wood construction has been increasing by the governmental policy called

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"green growth" followed by increasing interest in wood construction. This situation has been accelerated by worldwide regulation such as Green House Gas Mitigation and Low Carbon Footprint. Recently, some construction companies are throwing effort to develop timber housing complex in suburban area for meeting increasing demands. However, high cost and poor knowledge about wood can be obstacles for customers to hesitate making their choices.

Cross laminated timber (CLT) was first developed in 1970s in Europe, but it took 30 years to commercialize and start mass production along with increasing concern on environmental issues. As proved in Europe, CLT can be an outstanding solution for stationary timber construction market in Korea. It can be applied to single housings, multi-story housings and also industrial buildings which require long span. Moreover, CLT was proven to be more economical than concrete building when it comes to mid-rise building. It is easy to construct and fast in construction than concrete building. Less waste and embodied energy make CLT more environment-friendly material.

However, there is no specific standard for CLT because it had been developed in industrial section. So many researchers in Europe and North America has been working on developing standard for making CLT and it is still under development or draft is completed. Two important things affecting performance of CLT are timber and adhesive. Timber should be selected by their structural requirement and adhesive should be selected by their end-use environment. Regardless of their environment in use, adhesive should not fail and has to satisfy specific requirement. So far, industrial section is using the adhesive such as PUR (Poly urethane resin) and PRF (Phenol resorcinol formaldehyde) commonly used in glulam and the proposed drafts also suggests to evaluate the performance of adhesive in CLT by the same method as glulam. But Blass H. J. (2011) reported that structural behavior of CLT is governed by rolling shear and failure by the rolling shear occurs only in cross laminating. Therefore, this study is focusing on difference in evaluation of adhesive performance between glulam and CLT. Moreover, it is aimed to investigate whether Korean standard for glulam is appropriate for CLT.

2. Materials and Methods

2.1. Materials

Japanese Red pine (*Pinus densiflora*) was selected as species for making samples and the moisture content and oven-dried density were 12.16 ± 0.73% and 460 ± 20 kg/m^3, respectively. One-component Polyurethane (PUR) was selected as adhesive because it is commonly used for CLT in Europe and convenient as it does not require hardener. P84 (OTTO CHEMIE, Germany) has very high bond strength and has been used to manufacture laminated wood products and it has already passed weathering resistant test (DIN EN 204-D4). Technical Data Sheet (TDS) which includes detailed bonding condition has to be presented by each manufacturer of adhesives and TDS of P84 is shown in Table 1. Therefore, specimens were made following the TDS and KS F 3021 (Structural Glued Laminated Timber) because there is no certified adhesive standard for cross laminated timber until now.

2.2. Block Shear Test

Block shear test was conducted following KS F 3021 to evaluate bonding performance of glue line. The performance is evaluated by shear strength of glue line and percentage of wood failure. Test specimen were manufactured in two

Table 1. Technical Data Sheet of P84

	P84
Open time (min)	20
Processing temperature (°C)	not below +5
Viscosity at 23°C (mPas)	2,000
Density at 23°C (g/cm^3)	1.23
Pressing time at 23 °C (min)	30
Pressure (kg/cm^2)	10
Amount of adhesive (g/m^2)	175
Recommended wood humidity (%)	12 (8 - 16)
Shelf life at 23°C/50% RAH in original, unopened packagings (months)	12

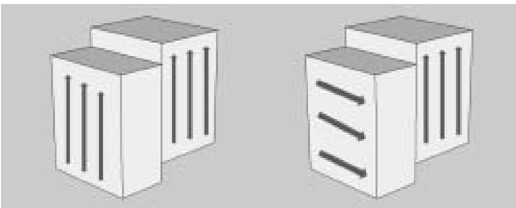


Fig. 1. TSchematics of Specimen (Parallel laminating - left, Cross laminating - right).

different ways to evaluate cross laminating effect on bonding performance as shown in Fig. 1. Universal testing machine (Zwick, max 980N, Germanu) was used to apply load to a specimen and the loading rate was 2 mm/min.

Adhesive performance can be evaluated by measuring shear strength and wood failure. Different requirements are specified for each group of species in KS F 3021 related to glulam. The species of this study *(Pinus densiflora)* is categorized in group B, therefore shear strength should be higher than 7.1 N/mm^2 and wood failure should be larger than 65% to satisfy Korean Standard.

The first standard which was implemented in the world, EN (Euro code) 16351 draft, also requires to satisfy the requirement of glulam. The requirement is presented in Table 3.

Table 2. Standard for Glu-lam about Shear Stress and Wood Failure in Block Shear Test (KS F 3021)

SpeciesGroup	Shear Stress (N/mm^2)	Wood Failure (%)
A, B	7.1	65
C	5.9	65
D	5.3	70

A: Larch, B: Pine, C: Nut Pine, D: Cedar

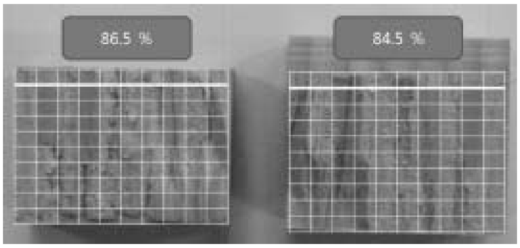


Fig. 2. Measuring of Wood Failure (Parallel laminating, Specimen No. 12).

2.2.1. Shear Strength and Wood Failure

Shear strength was calculated using eqation (1).

$$f_v = \frac{P_{\max}}{A_v} \tag{1}$$

where,

f_v : shear strength (N/mm^2)

P_{max} : Maximum load (N)

A_v : Shear area (mm^2)

Wood failure was measured in 0.5% level by making grid and applying it on both bonding surface. Then the average value of both sides were taken as wood failure according to ASTM D 5226-99. Wood failure can be calculated using eqn. 2.

$$R_{wf}(\%) = \frac{A_{wf}}{A_g} \times 100 \tag{2}$$

where,
R_{wf} : Wood failure (%)
A_{wf} : Area of wood failed (mm^2)
A_g : Total bonding area (mm^2)

3. Results and Discussion

3.1. Shear strength

Fig. 3 shows shear strength according to different laminating direction. Average shear strength for parallel laminating was 10.27 ± 0.67 N/mm^2. On the other hand, average shear strength was 3.5 ± 0.49 N/mm^2 in case of cross laminating. That is, cross laminating decreases shear strength of adhesive to 66% of parallel laminating when adhesive was applied on *Pinus densiflora.* Specimen which bonded in parallel direction satisfied KS of glulam. However, CLT standard proposed by EN suggests to conduct the experiments related to bonding performance with the specimen made in the same way of glulam which is parallel to the adjacent layer. Therefore, the result of this study showed that the bonding performance satisfied the CLT standard. However, there was large difference of shear performance between cross lamination and parallel to grain lamination. This result indicated that the shear performance of bondline does not contribute to shear strength measured by block shear test. The lower shear strength can be explained by the fact that rolling shear strength in cross section plane is much lower than normal shear strength in radial/tangential plane. As Blass (2000) reported, rolling shear strength is 1/10 of normal shear.

3.2. Wood Failure

Wood failure according to laminating direction is shown in Fig. 4. Wood failure for parallel lamination and cross lamination were 92.46 ± 8.67% and 90.3 ± 10.22%, respectively. There was no significant difference in wood failure

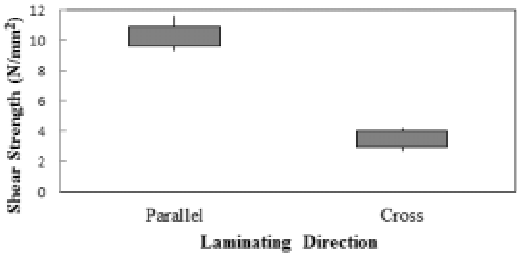


Fig. 3. Difference in Shear strength according to laminating direction.

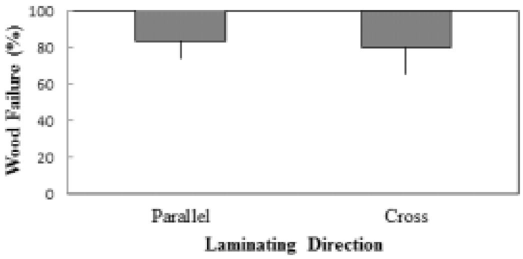


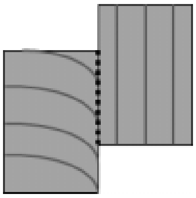
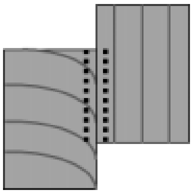
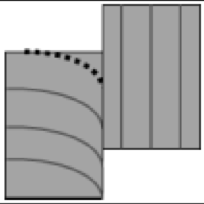
Fig. 4. Difference in wood failure according to laminating direction.

Table 3. Minimum wood failure percentages relating to the shear strength f_v[a]

	Average			Individual values		
Shear strengh f_v (N/mm^2)	6	8	$f_v \geq 11$	$4 \leq f_v \leq 6$	6	$f_v \geq 10$
Minimum wood failure percentage (%)[b]	90	72	45	100	74	20

[a]For values in between linear interpolation shall be used
[b]For average values the minimum wood failure percentage shall be: 144-($9f_v$).
For the individual values the minimum wood failure percentage for the shear strength fv ≥6 N/mm^2 shall be: 153.3-($13.3f_v$).

Table 4. Failure modes of wood-wood specimen

Mode	Ⅰ	Ⅱ	Ⅲ
Failed Material	Adhesive	Wood	
Schematic Drawing	Normal	Normal	Rolling Shear
			

according to laminating direction. Wood failure was high enough to pass KS of glulam for both parallel and cross laminated specimen.

3.3. Failure Mode

Failure modes are categorized into three modes according to the failed material and failure type and it is shown in table 4. Mode Ⅲ is failure of bond and mode Ⅱ, Ⅲ are failure of wood. Mode II is failure of adjacent woods along with bond surface and mode III is failure of wood along with its annual ring. Results showed that all parallel laminated specimen had failed in mode Ⅱ that wood of both sides of specimens failed. On the other hands, 40% in specimen ofthe cross lamination had failed in mode Ⅲ which meant the failure of wood along with their annual ring. Rolling shear is common when cross laminated timber is subjected to out-of-plane bending behavior. And there are various causes influencing rolling shear such as sawing pattern, annual ring width, type of adhesive and type of loading. All specimen which showed the mode Ⅲ failure had the same annual ring orientation as Fig. 5 showed. There was no specimen showing mode Ⅰ failure which meant poor bonding.

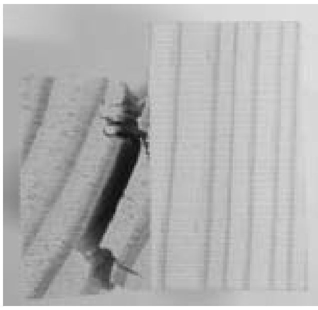


Fig. 5. Rolling shear failure of cross laminated specimen.

4. Conclusion

This study was conducted to investigate the difference of bonding performance according to laminating direction. Moreover, it was investigated whether or not Korean Standard for glulam is appropriate for CLT. It was verified that there is significant difference between cross lamination and parallel lamination on shear performance. The conclusions are as follows:

(1) The current glulam standard for evaluating bonding performance is not appropriate for CLT.
  - The first criterion to evaluate glue performance, “shear strength” is not appropriate for testing CLT. Cross laminated specimens showed 1/3 shear strength of parallel to grain laminating. The shear strength measured by

block shear test seems to represent shear performance of wood itself.

- There was no significant difference in wood failure between cross lamination and parallel to grain lamination. Thus, wood failure can be used as a requirement of CLT bonding.

(2) Mode Ⅱ, Ⅲ failure occurred and mode Ⅲ failure occurred only in specimen with same annual ring orientation.

Based on the results, difference in shear performance of adhesive from laminationg direction should be included when evaluating adhesive performance of CLT correctly and should be considered as an important factor.

Acknowledgment

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