 http://dx.doi.org/DOI : 10.5658/WOOD.2011.39.5.437

Evaluation of Friction Properties According to Normal Force and Direction of Wood Grain in Real Contact Area*1

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ABSTRACT

In Korea, there has been a traditional post and beam wood construction with large roof load. Because a large friction is generated in wooden joint or members, it is important to evaluate the friction between wood members according to wood direction. Because most of studies have been concerned with friction between wood and steel, excluding effect of real area of contact, there are a few studies on the friction between wood members. The object of this study was to evaluate friction or coefficient of friction according to normal force and real area of contact of wood. With Japanese larch (*Larix kaempferi*) test specimens, five steps of normal force and combinations of test were prepared. Results indicated that normal force had almost no affection on the friction, however there was difference about friction or coefficient of friction according to real contact conditions of wood grain and contact area.

Keywords : friction, coefficient of friction, real area of contact in wood, normal force, wood grain

1. INTRODUCTION

Friction can be defined a resistance force that makes it difficult for thing to move freely when they are contacting each other or moving in different direction. In case of wood, the coefficient of friction in wood is related to various factors including tree species, slope of grain, moisture content, temperature, coarseness of contacting surfaces, and loading speed[1]. However, a few studies have empirically evaluated the relative significance or roles of these factors. McKenzie and Karpovich investigated the relationship between the coefficient of friction and species of tree, coarseness of contact surfaces, and load speed. The study showed that coefficient of friction had range of 0.1 to 0.65 according to the species of tree and roughness of contact surfaces. And as load speed increased, coefficient of friction reduced constantly. Murase measured the coefficient of friction at 0.58 for western hemlock[2], while Inayama applied estimated values of 0.4 to 0.5 for an analysis of Japanese traditional shear walls[3]. And, when performance of connection was analyzed, reference value of friction or coefficient of fiction was only used. It might be no problem to analyze connection, because friction did not almost occur in mecha-

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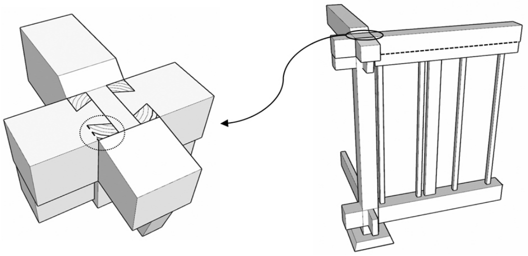


(a) (b)

Fig. 1. Detail drawing of joint (a) and wood frame (b) in Han-ok.

nical fasteners of light-framed wood structure. But Korea is not the case. Because the roof load of Han-ok which is Korean traditional wood construction, is much bigger than other type of wood construction. So friction developed in joint of Han-ok would be much bigger than that of light-framed wood structure. Further more, because joint of Han-ok is made of wood, friction could be different according to members which consist of joint. For example, friction or coefficient of friction which is developed between transverse section and radial section (straight line in dotted circle) shall differ from that which is developed between radial sections (dotted line in dotted circle), as shown in Fig. 1(a). Also, friction could arise between members (dotted line), as Han-ok is post and beam construction likes Fig. 1(b). So, it can be said that friction is very important factor in Han-ok considering with the shape of joint without any fastener and heavy vertical load.

Also, friction showed significant effect on stress distribution of the joint. Namely, stress distribution of the joint is simply distributed by compression, tension and shear according to the load when coefficient of friction is small. On the other hand, very complex analysis is required, because additional friction is distri- buted on each surface according to the coefficient of friction. Therefore, different friction properties should be used on each case when the direction of wood grain is diverse like traditional joint.

Results of previous researches had extensive range of friction coefficient because of moisture contents, species, surface condition, experimental error and so on. So the data did not used in structural analysis of Han-ok with various shape joints. Therefore, objective of this study is to evaluate friction properties according to the normal force and the direction of wood grain in real contact area with the specimen which are prepared exquisitely in laboratory condition.

2. MATERIALS AND METHODS

2.1. Materials

Japanese larch (*Larix kaempferi*) was used to assess friction forces. Surface area of each sample was 140 × 150 (mm). Samples were manufactured using a power saw (DW 718-QS, Germany) and electric plane (2012NB, Japan) to reflect the typical character of mechanical works. The materials were cut to get target area from 2 × 6 (in.) sawn lumber. Load speed of power saw was 3,600 rpm. And then, those were planed to 30 mm thick using electric planer. Load speed of electric planer was 8,500 rpm, and feeding speed of that was 0.14 meter per second. Because temperature and humidity affect the results of friction tests, all test samples were stored at a temperature and humidity of 24°C and 65% until they showed no change in weight. Specific gravity and moisture content were assessed for all test samples and the results were 0.53, 12%, respectively.

2.2. Testing Methods

Test assembly for determining the coefficient of friction for wood came from American Society of Testing Materials (ASTM) D 2394,

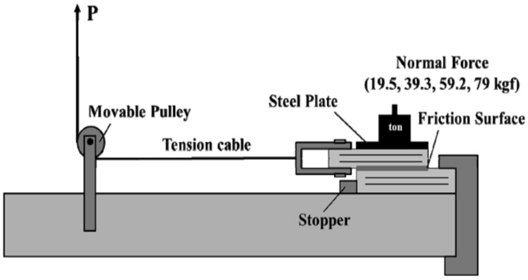


Fig. 2. Equipment set-up for friction force experiments.

"Standard Test Method for Simulated Service Testing of Wood and Wood-Based Finish Flooring"[4], and ASTM G 115, "Standard Guide for measuring and Reporting Friction Coefficients"[5], was used to analyze results of friction test. The equipment used for experiment is illustrated in Fig. 2. As shown in Fig. 2, using pulley and tension cable, specimens were loaded by Universal Testing Machine (UTM, Zwick, Capacity: 10 ton) at the speed of 1 mm/min which is same load speed of general strength test of wood. Through UTM, load and head travel were recorded. After that, maximum static friction force, kinetic friction force were evaluated, when steady normal force (restraint force) was maintained between materials. A normal force which was divided into four stages was applied constantly using a balance weight. To apply uniform load to materials, the balance weight was installed on a steel plate which was made in same scale of friction surface size.

As shown in Fig. 3, the friction surfaces were divided into three segments depending on the direction of wood according to load direction: L_{LR} (longitudinal direction on LR plane), R_{LR} (radial direction on LR plane), R_{RT} (radial direction on RT plane). Five combinations were used: L_{LR}-L_{LR}, L_{LR}-R_{LR}, L_{LR}-R_{RT}, R_{LR}-R_{LR} and R_{LR}-R_{RT}. As mentioned above, these are all case of combinations that can be occurred in joint or between members of Han-ok. For each case,

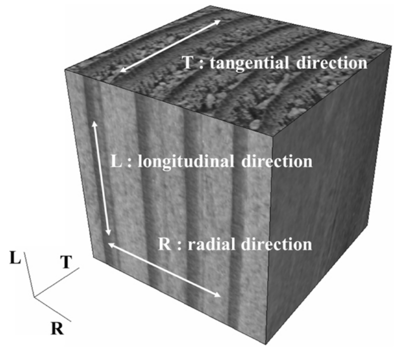


Fig. 3. Load direction relative to wood grain on contact surfaces.

testes were repeated five times.

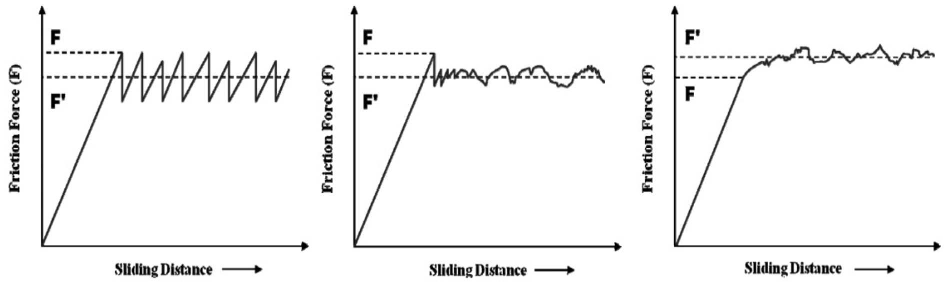
During loading, maximum static friction forces were estimated when test samples started moving. And kinetic friction forces were estimated during test samples were moving. Then, the coefficient of friction was calculated as follows.

$$F = \mu N \tag{1}$$

F: Friction Force
μ: Coefficient of Friction
N: Normal Force

The maximum static friction force and kinetic friction force showed difference according to the friction force-sliding distance curve patterns. Fig. 4 shows the common friction curve, and F and F′ indicate maximum static friction force and kinetic friction force, respectively. In Figs. 4(a) and 4(b), kinetic friction force was determined by calculating the average maximum and minimum values. But in Fig. 4(c), the maximum static friction force remained unclear. In this study, kinetic friction forces were calculated by average maximum and minimum values, because only repetitive stick-slip events (as shown in Fig. 4(a)) were observed.

During stick-slip, digital camera was used to



(a) (b) (c)

Fig. 4. Friction patterns of friction force and sliding distance curve.

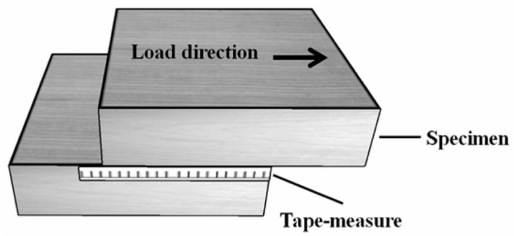


Fig. 5. A set of specimens with tape-measure.

take a picture. Whenever one stick-slip had been developed, a picture was taken. These pictures were used to measure the average moving distance of specimens when one stick-slip was developed. As shown Fig. 5, tape-measure was installed on under specimen to check an accurate distance of specimen. Error range of tape-measure was ± 0.5 mm.

3. RESULTS and DISCUSSION

Friction test between wood surfaces were performed according to normal force (restraint force) and the direction of wood. As mentioned, normal forces showed four steps (19.5, 39.3, 59.2, 79 kgf) and combinations of contacting surface were five.

Table 1. Average displacement and annual ring width during stick-slip in LLR-RLR combination

Number	$D_{D.C}$[a] (mm)	Annual ring width (mm)
1	0.89	6.57
2	0.79	6.31
3	0.44	6.03
4	0.38	3.36
5	0.46	9.92

[a] Average moving displacement of specimen which was gain from digital camera.

3.1. Consideration in The Form of Friction Force-sliding Distance Curves

In this study, friction force-sliding distance curves of friction of wood showed the same pattern as shown in Fig. 4(a), but it was found that displacement changed as stick-slip occurred, despite of the same experimental conditions. Stick-slip usually associated with the increasing of relative velocity followed by the decreasing of coefficient of friction[6]. So, it was determined that phenomenon of stick-slip changed by not only the relative velocity but also the characters of specimen. Accordingly when phenomenon of stick-slip developed, average displacement which was gained from digital camera and annual ring width of under specimen which made up

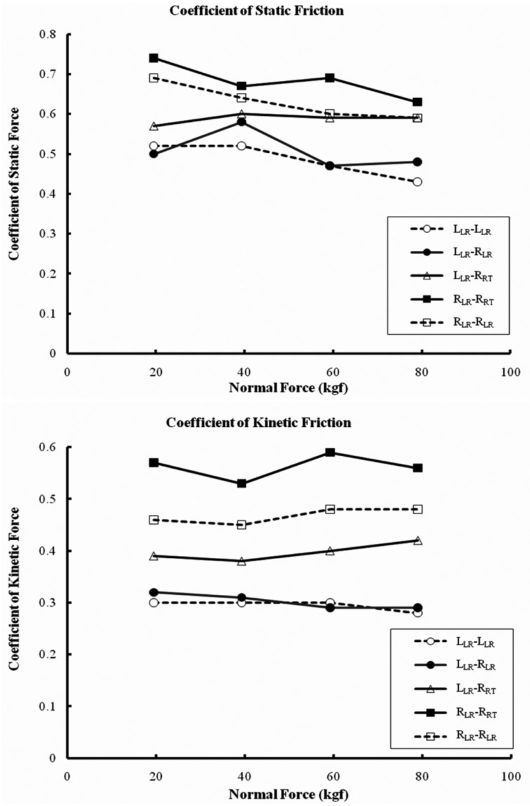


Fig. 6. Coefficient of friction according to normal force.

contacting surface were shown in Table 1.

Though annual ring width of number 5 was the largest, average displacement which was gained from digital camera was not the longest. But usually, it could be confirmed that as annual ring width got smaller, average displacement got shorter. Therefore, it could be said that not only the relative velocity but also the annual ring width had effect on stick-slip in wood. Annual rings were formed from the consisting of early wood and latewood. It can be easily found that latewood shows small radial diameter and thick cell wall, while early wood shows large radial diameter and thin cell wall through microscopic analysis. However scientists have been found that the cause of early wood and latewood formation and the mystery is not entirely solved[7]. But it could be said that consisting of early wood and latewood could have an effect on stick-slip in friction. Further research is required.

3.2. Evaluation of Friction according to Normal Forces

The relationships between coefficients of static and kinetic friction and normal forces (restraint forces) are shown in Fig. 6.

In case of coefficient of static friction, it tended to decrease, as normal force increased (Fig. 6). These results indicate that the friction coefficient maintains the same value even if different loads were applied to a structure which generates friction because the biggest difference between maximum and minimum value was only 0.11 in coefficient of static friction. However, due to the limitation of laboratory equipment, the experiment could not be conducted under much bigger normal force, yet additional test needs to be conducted to investigate relationship between coefficient of static friction and big normal force, because much larger roof load is corresponding to normal force in Han-ok. According to normal force, coefficient of kinetic friction was almost constant.

3.3. Evaluation of Friction according Real Area of Contact

The relationship between friction coefficient and the direction of wood is shown in Fig. 7.

The direction of wood exerted a little influence on coefficients of friction when longitudinal direction on LR plane (L_{LR}) met the same surface or radial direction on LR plane (R_{LR}). However, when radial direction on LR plane (R_{LR}) met the same surface or radial direction on RT plane

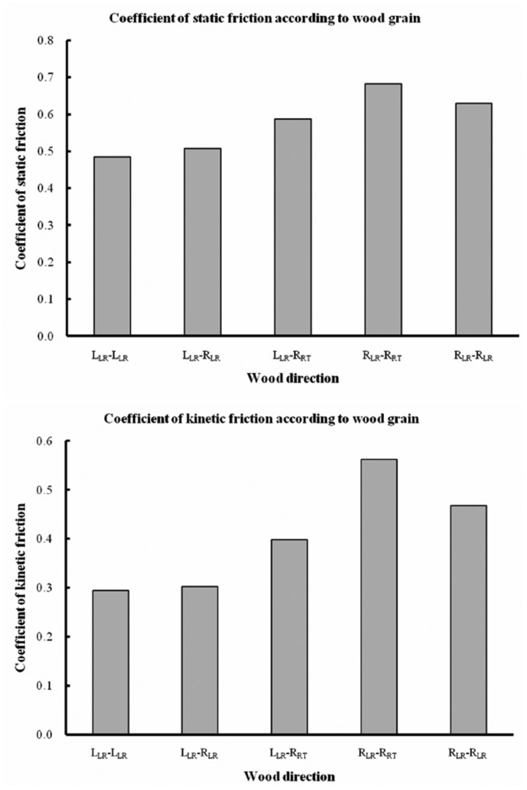
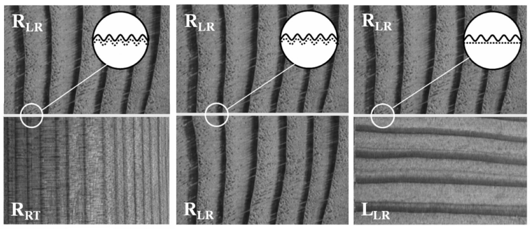


Fig. 7. Coefficient of friction according to wood grain.



(a) (b) (c)

Fig. 8. Comparison of real contact area according to wood grain.

(R_{RT}), coefficient of friction tend to increase significantly. Specially, the largest coefficient of friction appeared in case of radial direction on LR plane (R_{LR}) met radial direction on RT plane (R_{RT}). That is, the results of friction coefficients were R_{LR}-R_{RT} > R_{LR}-R_{LR} > L_{LR}-R_{RT} > L_{LR}-L_{LR} ≒ L_{LR}-R_{LR} in order of magnitude.

If the directions of grain in two contacting materials were arranged perpendicularly with load direction (R_{LR}-R_{RT}, R_{LR}-R_{LR}), the friction surfaces are greatly closed to each other (Fig. 8(a) and 8(b)). So, large friction or coefficient of friction was generated. In wood, roughness is generated by early wood and late wood. And a heavy roughness is more likely to occur in transverse sections. On the other hand, two materials contacted smoothly when the wood was arranged in longitudinal direction on LR plane (Fig. 8(c)). From this, differences in friction were generated by real area of contact.

As mentioned above, roof load of Han-ok is large, and members are assembled post-and-lintel construction method. So it could be said that it is important to evaluate friction or coefficient of friction according to direction of wood. And evaluation of friction or coefficient of friction according to real area of contact will be helpful to analysis the structure of Han-ok as well as wooden structure.

4. CONCLUSIONS

Results of study which was conducted on friction generated between wood surfaces according to the wood grain and normal force were as follows.

- There is no change of friction coefficient according to normal force.
- In case of the material which loaded perpendicular to grain of wood, friction force was large, because of real contact area which was generated by early and late wood.

Joints of Korean traditional wooden structure were manufactured with mortise and tenon joint. So, the contact area between wood members has various conditions such as wood grain direction, species, ratio of early and late wood, load condition and so on. Furthermore, the friction has not been considered in structural analysis and design of wood structure. The results of this study indicate that the friction was generated in wood to wood joint with normal force and it is different in the direction of wood grain. Han-ok was composed with many different wood members such as post, beam, lintel, various joints, so directions of wood grain are various in respective contact area. For the accurate structural analysis and design, frictional properties which were evaluated in this study should be utilized according to the direction of wood grain.

ACKNOWLEDGMENTS

This study was carried out with a grant from the Forest Science and Technology Projects (Project No. S120710L100110) funded by the Korean Forest Service.

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