**A THESIS FOR THE DEGREE OF MASTER SCIENCE**

# Development of Half-Blind Dovetail Joint of Laminate Floorings by Computer Aided Analysis

컴퓨터 이용 분석에 의한 강화마루 바닥재용 반턱장부 접합부 개발

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이 논문을 농학석사학위 논문으로 제출함

2013년 12월


서울대학교 대학원

산림과학부 환경재료과학 전공

이 주 희


이주희의 석사학위 논문을 인준함

2013년 12월

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**논문제목** : Development of Half-Blind Dovetail Joint of Laminate Floorings by Computer Aided Analysis

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# Abstract

## Development of Half-Blind Dovetail Joint of Laminate Floorings by Computer Aided Analysis

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As pursuing improvement of life quality interest in raw material and joint system of flooring, which is in contact with the most human of living space, has increased. Wood is prominent sound absorption and beautiful pattern flooring material. Sawn wood is inappropriate for floor heating system because of low heat conductivity and deformation by distortion and cracks. To make up for the weak points, laminate flooring was developed. In early 1990's, click profile joints was developed mechanical locking system which was combined each other without adhesive. Click type laminate flooring has grown significantly in popularity, because it is easier to install and maintain than traditional hardwood flooring. However, the floor heating system caused some problems at laminate floorings. When floor heating is operated, laminate flooring is shrunk. In this case, tensile strength of click-profile flooring becomes weak and then a gap occurs at each joint. Another problem is low heating velocity because of thick floorings.

In this study, new design of dovetail joint was developed for minimize thickness of flooring. Lower side of the dovetail joint was designed to be connected apart from 4mm at the bottom. And upper side was designed to form shape of oblique line to prevent sticking out floorings upwards. And every edge of dovetail joint was cut round to assembly angling combination. Tenon and mortise of

dovetail joint was connected horizontally and vertically. In comparison with click joint, which is composed of 3 protrusions (two of mortise and one of tenon) dovetail joint is composed of 2 protrusions (one of mortise and one of tenon). So, thickness of dovetail joint could be reduced.

Heat performance of flooring was analyzed by computer aided engineering (CAE). Because joint profile was complex experimental, analysis of joint structure was limited. But, CAE (Computer Aided Engineering) makes it possible to predict structural performance of joint.

As result of floor heating simulation, surface temperature of dovetail flooring was 41.5℃ and dovetail joint temperature was 40.7℃. Then, surface temperature of click flooring was 40.6℃ and its joint temperature was 36.5℃. Temperature of dovetail flooring was higher than click flooring. The reason was that heated air from heat film was leaked along the click joins in horizontal direction. Heat loss from the part of click joint occurred more than dovetail joint. In experiment, the temperature of dovetail joint was 38℃ and temperature of click joint was 37℃. Temperature of dovetail joint was 1℃ higher than temperature of click joint.

Binding force of dovetail joint was higher than click joint. Because thin dovetail joint could be connected each other with strong binding force, which is similar to it of click joint by dovetail joint, thickness of floor could be decrease. This, also, could lead to reduce manufacturing and heating cost as well as reducing heating time.

**Keywords: Click flooring, Computer Aided Engineering, Dovetail joint, Heat transfer, Laminate floorings**

**Student number: 2011-23505**

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# 1. Introduction

## 1.1. Background

Ondol is Korean transitional heating system, and it is floor heating system. Floor heating system was passed down sedentary lifestyle. For a long time, Korean who has lived sedentary lifestyle is closely related with floor in building for residence. Floor was the closest medium that was evaluated by thermal comfort (Won et al, 2001).

In case of swan wood flooring, swan wood is promoted a pleasant residential environment due to control moisture and wood natural grain and comfortable texture make people stable. Furthermore, wood flooring is improved walking fatigue by absorbing a shock. However, when floor heating is operated, wood which is usually used insulator is low thermal conductivity, so, heating rate is low too. Therefore, it is that resident is unsatisfied and heating energy is inefficient (Song et al, 2000).

Laminate flooring simulates wood with a photographic applique layer under a clear protective layer. The inner core layer is usually HDF (High Density Fiberboard) or MDF (Medium Density Fiberboard). Laminate flooring is easier to install and maintain more than traditional surfaces such as hardwood flooring. It is durable relatively. The greatest advantage of laminate flooring is locking system which is combined each other without adhesive. It may also have the advantages of costing less and requiring less skill to install than alternative flooring materials. However, most Korea companies which are using click joint pay royalty to foreign corporation which has click joint patent (Park. et al, 2009).

In Europe, convection heating like fireplace has been widely used for heating system in house. And the maximum heating temperature of floorings is 28℃. In comparison with Europe, the average heating temperature of flooring surface of Ondol is around 30~35℃(Kim, 2007). The floor heating system caused some problems at laminate floorings. When floor heating is operated, laminate flooring is shrunk. In this case, binding force of click-profile flooring becomes weak and then a gap occurs at each joint. Another problem is low heating velocity because of thick floorings.

Computer Aided Engineering is written as a character in simplified form CAE. CAE is the broad usage of computer software to aid in engineering tasks. It includes computer-aided design (CAD), computer-aided manufacturing (CAM) and so on. CAE tools are very widely used. It has enabled the engineer to reduce product development cost and time while improving the safety, comfort and durability of product. The predictive capability of CAE tools has progressed to the point where much of the design verification is now done using computer simulation rather than physical prototype testing.

## 1.2. Objective

The purpose of the paper is as follows.

First, to enhance performance of heat and strength, new flooring joint which was applied dovetail joint was developed and manufactured.

Second, new dovetail joint was simulated and analyzed heat performance by computer aided engineering. To secure reliability of simulation, floor heating was experimented in comparison with simulation.

Finally, thickness of flooring was reduced and evaluated. Reducing thickness of flooring could be cost reduction and fast heat transfer. Tensile strength of joints was measured that it was feasible to reduce thickness.

# 2. Literature review

## 2.1. Flooring

### 2.1.1. Solid wood flooring

Solid wood floorings are manufactured by natural wood, the specie is uaually decideous tree. As shpaes, solid wood floorings are categorized strip floorings and plank floorings. Solid wood flooring has low thermal conductivity and high heat insulation property as compared with another materials because anatomical structure of wood is reticulate structure crossed cell wall and void volume. So solid wood floorngs which are low floor heating effect are not used for home used floorings, whereas it has advetaged outstanding shockproof so that commerical buildings are usually constructed like sports centers or schools (Jung. et al, 2000). Preference of solid wood floorings has increased by smooth texture and natural wood grain. However, problems of solid wood flooring are shrinkage, swelling cracks and so on. The survey of using solid wood flooring showed that 52.6 percent of those consumers wanted to improve wood flooring deformation by moisture (Kim, 2003).

## 2.1.2. Wood-based flooring

Due to limit supplying solid wood, substrate of wood-based floorings is manufactured by plywood, particleboard, and fiberboard and so on.

### 2.1.2.1. Plywood flooring

Plywood flooring is a manufactured wood panel made from thin or thick sheets of wood veneer. Thickness of plywood flooring is less than 10mm; it is called thin sheets flooring. And thickness of plywood flooring is more than 100mm; it is called thick sheets flooring. Thick sheets flooring cannot use floor heating. Surface is glued figured veneer on the top layer. In case of surface figured veneer that surface thickness is more than 2mm, sometimes it is called solid wood flooring. Surface figured veneer shows different grain by veneer peeling and colors by sapwood or heartwood.

Thin sheets flooring is installed to glue subfloor and flooring. Thick sheets flooring is installed not only to glue but also to float. Floating installation is that subfloor and flooring are floated each other. Originally, adhesive installation of plywood flooring was the way flooring was constructed on the plywood subfloor in Japan. To bring the type of installation into the country, the way has been developed to install on the concrete subfloor. However, concrete subfloor is not flat horizontally and it is affected temperature and humidity by floor heating system. Because of strong adhesive force, deformation of plywood flooring is reduced and it is not sensitive by moisture. But it has a short life.

### 2.1.2.2. Laminate flooring

Laminate flooring is a multi-layer synthetic flooring product fused together with a lamination process. Laminate flooring simulates wood with a photographic applique layer under a clear protective layer. The top layer is laminated HPL (High-pressure laminate) or LPL (Low-pressure laminate) and the inner core layer is usually HDF (High Density Fiberboard) or MDF (Medium Density Fiberboard). HPL is manufactured through fusing multiple layers of impregnated paper under high pressure and temperature to create a hard wearing, durable and hygienic surfacing material. As surface materials, laminate flooring is classified HPL flooring which is made high-pressure laminated and DL (Direct laminate) which is made low-pressure laminate.

Laminate flooring is constructed floating installation regardless of floor heating system and it is used by commercial and residential buildings. It has grown in popularity as excellent property in comparison with solid wood flooring (TAPPI, 2006).


**Figure 2-1. Plywood flooring**

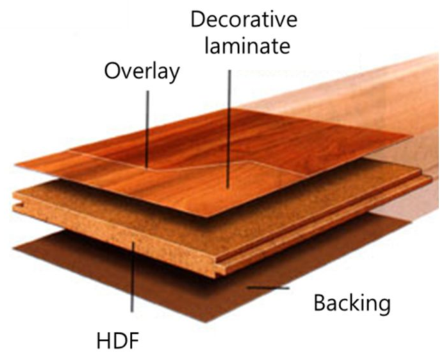



**Figure 2-2. Laminate flooring**[1]

[1] http://blog.naver.com/richardcha

## 2.2. Joints

### 2.2.1. Dovetail joint

Dovetail joint is one of the transitional joint and have been used for a very long time. It is a fan-shaped tenon that forms a tight interlocking joint when fitted into a corresponding mortise. Dovetail joint is a joint technique most commonly used in woodworking joinery including furniture, cabinets, log buildings and traditional timber framing. A series of pins cut to extend from the end of one board interlock with a series of tails cut into the end of another board. The pins and tails have a trapezoidal shape.

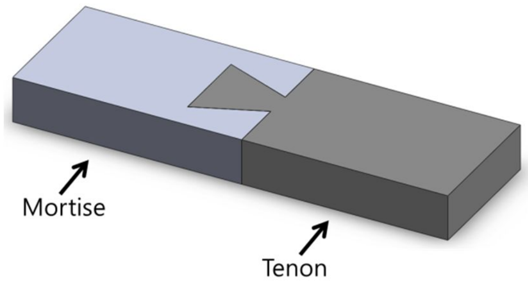



**Figure 2-3. Model of dovetail joint**

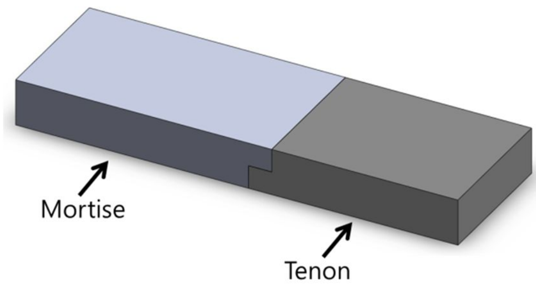



**Figure 2-4. Model of secret mitred dovetail**

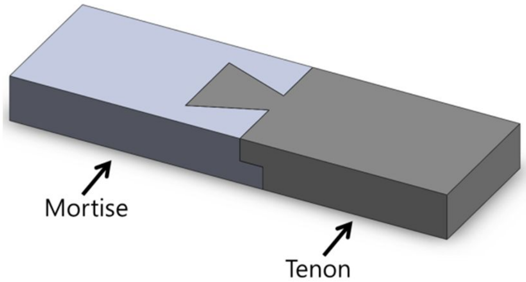



**Figure 2-5. Model of secret mitred dovetail (lower side view)**

A half-blind dovetail is used when the craftsman does not wish end grain to be visible from the front of the item. The tails are housed in socket in the ends of the board that is to be the front of the item so that their ends cannot be seen.

Dovetail joints have strong tension strength horizontally. The joint is maintained itself unless stiffener or adhesive. Because of interlocking structure between pins and tails, dovetail joint had resistance from stress, so it was the strongest withdrawal strength among the other joints (Su et al, 2007). Mortise and tenon joint was dependent on adhesive, but dovetail was not.

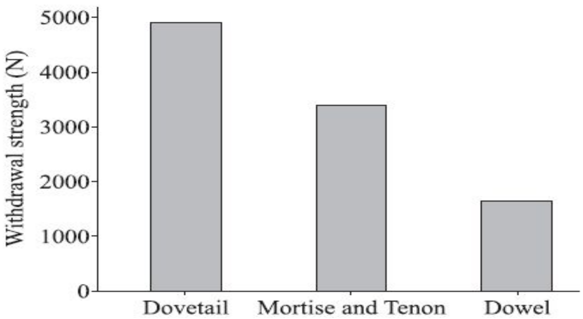



**Figure 2-6. Withdrawal strength of Dovetail, Mortise and Tenon and Dowel**

Han et al. (2001) reported that the longer length of dovetail, the weaker binding performance but the bigger deformation. The reasons were frictional area and clamping force.

Song et al. (2008) studied that lager area and high stickiness of dovetail joint result the lowest stress distribution stably. It was that sufficient frictional area by length of dovetail and connects of stickiness by tight dovetail and dovetail groove prevented clamping force loss. Due to longer dovetail joint length, joint stress was low but deformation of joint was increased.

Kazunari et al. (2006) researched tilt angles of dovetail. While tan$\theta$ was one third, it was 25~30% larger than one sixth, and it was about 50% larger than one second. In shear strain, stress concentration of dovetail was distinctly appeared by larger tilt angles.

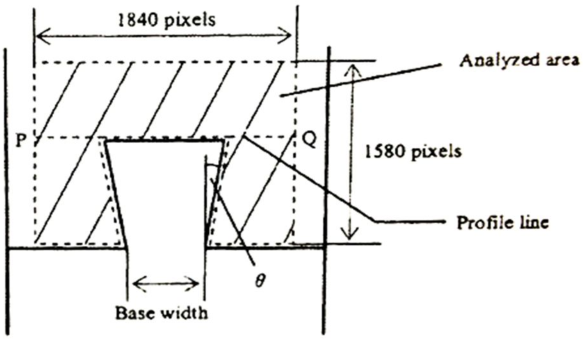



**Figure 2-7. Diagram of dovetail joint**

Su et al. (2007) reported that withdrawal strength of dovetail was strong by larger angle of dovetail.

**Table 2-1. Withdrawal strength of dovetail joint of hard maple**

| Dovetail angle ( ° ) | Withdrawal strength (N) |
|---|---|
| 8 | 4131 (859)* |
| 11 | 4276 (1096) |
| 14 | 4312 (657) |
| 17 | 4711 (037) |
| 20 | 4936 (909) |

* : Standard deviation

## 2.2.2. Flooring joints

### 2.2.2.1. Tongue and groove joint

The tongue and groove joint is used for re-entrant angles. Tongue and groove joints allow two flat pieces to be joined strongly together to make a single flat surface. It is a method of fitting similar objects together, edge to egde, used mainly with wood, in flooring, parquetry, panelling and similar constructions. Joint shage of flooring board shows Figure 2-6 and uses tongue and groove joint by KS F 3103 : 2007.

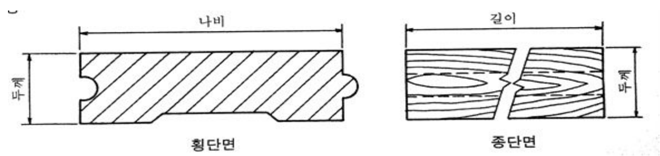



**Figure 2-8. Form of flooring (KS F 3103)**

In European standard EN 13329, tongue and groove joint is manufactured in flooring joint for installing easliy.

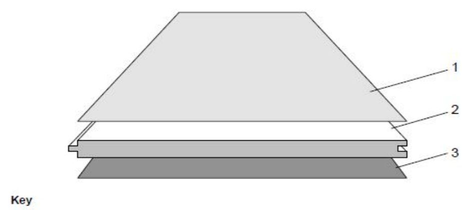



**Figure 2-9. Form of flooring (EN 13329)**

Tongue and groove joint is manufactured simply, but they are not connected unless adhesive. When adhesive is spread, tongue and groove joint have a large glue area. So it has strong binding force in compareson with other joints. However, adhesive causes problems for installation. Especially, adhisive is billowed by moisture or large amount. In this case, flooring installaion is constructed again.

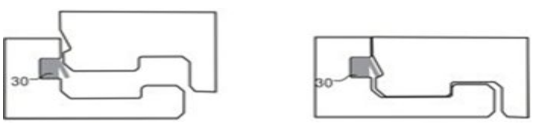
### 2.2.2.2. Click joint

Because established floorings were intalled by adhesive, difficult construction and indoor air pollution by adhesive were come to the fore disadventage. For solving the problems, gluelee locking system was develped. The system of joint was transformed tongue and groove joints, but was not used adhesive.

Nonadhesive coupling scheme was three kinds of methods ; Form-locking system without additional tightening elements, Force-fit system without additional tightening elements and Form-locking system without additional tightening elements. Firstly, form-locking system without additional tightening elements was formed shoulder construction by tongue and groove. It was slope rotating method and easy to assembly and disassembly. Secondly, form-locking system without additional tightening elements was also formed shoulder construction, but it was connected by snap method. It was easy to assembly, but excessive connection was occurred crack. Lastly, form-locking system with additional tightening elements was contsruted using clip-on type or elasticity combination device. This method had strong binding force, but the device produced cause of rising cost (Kim, 2007).

Form-locking system without additional tightening elements

Force-fit system without additional tightening elements




Form-locking system with additional tightening elements

**Figure 2-10. Example of glueless locking system**

Adventage of glueless locking system is easy to install so it could be reduce the time required install. In case of adhesive installation, it took 18~38 hours for drying adhesive, whereas nonadhesive installation took less 15~30% of installed time because it did not have to waite drying adhesive.

Mechanical locking system with the first laminate floorings from company named Alloc AS was displayed at the Trade Fair in Germany in January 1996. Then in 1997, Unilin Co. introduced a laminate floorings called Quick-step, patented Click-profile. These could be clicked into one another. Recently, most laminate flooring company have performed signing contract with click joint patent of Unilin or Berry Co.(Park et al, 2009).

# 3. Materials & Methods

## 3.1. Materials

### 3.1.1. Testing materials

Laminate floorings were used in this paper. Surface and backer layer were HPL, and core layer was HDF. The flooring joints were click joint patented Unilin Co.

**Figure 3-1. Laminate flooring**

Samples have a 200mm length, a 90mm width, an 8mm thickness and a joint of width 10mm like Figure 3-2. In case of 6 and 4mm thickness, laminate floorings were planed bottom side.

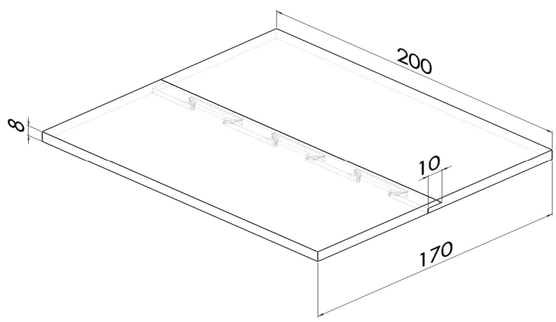



**Figure 3-2. Shape and dimension of floorings**

## 3.1.2. Production method

### 3.1.2.1. Computer Aided Design

#### 3.1.2.1.1. Geometrical Parameters of Flooring Joints

Dovetail joint was applied at flooring joint basically. For considering design and preventing to expose the dovetail patterns upper surface of flooring, the joint was constructed halving dovetail type.

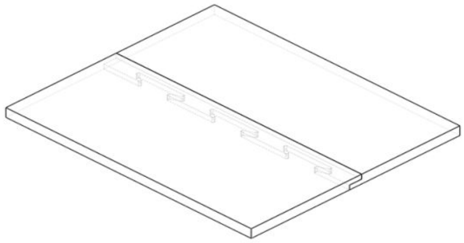


**Figure 3-3. Drawing of dovetail joint flooring**

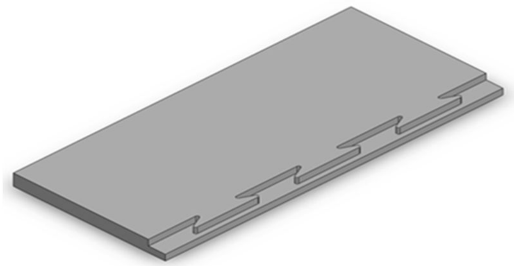


**Figure 3-4. Bottom view of dovetail mortise**

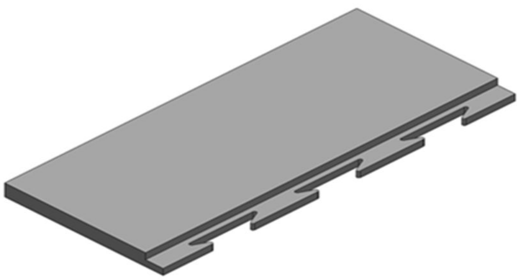


**Figure 3-5. Top view of dovetail tenon**

Dovetail and dovetail groove were same dimension like Figure 3-6. Due to machining property of CNC router, edge of dovetail was cut corner relief. The fillet size was a radius of 1mm.

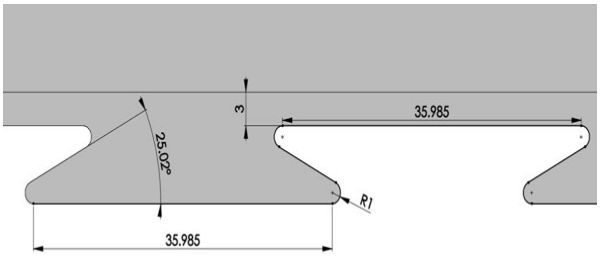



**Figure 3-6. Dimension of dovetail joint**

The dovetail joint was designed connect at apart 4mm from the bottom. And upper side was designed to form shape of oblique line to prevent sticking out floorings upwards.

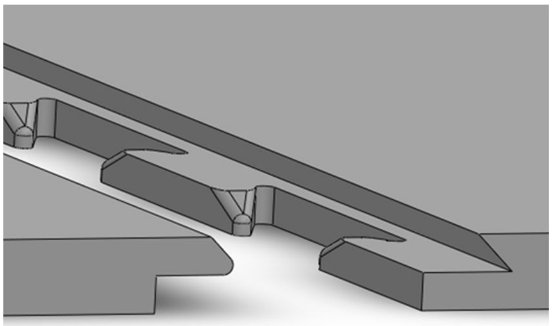


**Figure 3-7. Shape of oblique line**

**Figure 3-8. Side view of dovetail joint**

Most click joint was installed angling combination like Figure 3-9. It was to assembly easily. Unlike tongue and groove joint, click joint was manufactured round edge.

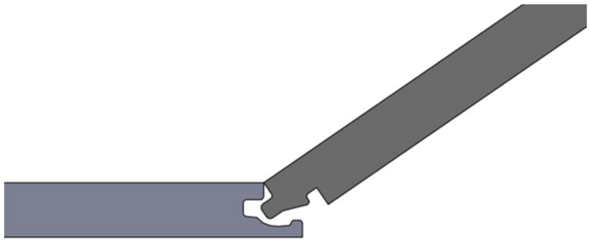


**Figure 3-9. Angling combination of click joint**

In case of dovetail joint, because of shape of oblique line, dovetail joint could not be combined up and down. Like click joint, every edge of dovetail joint was cut round to assembly angling combination. Figures 3-10 and 3-11 show geometry of dovetail joint.

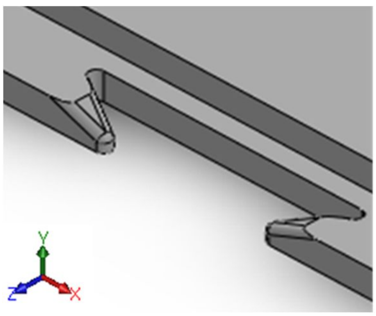



**Figure 3-10. Round cutting of tenon**

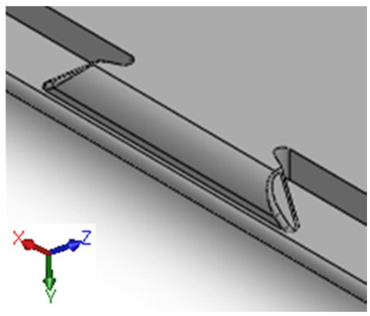



**Figure 3-11. Round cutting of mortise**

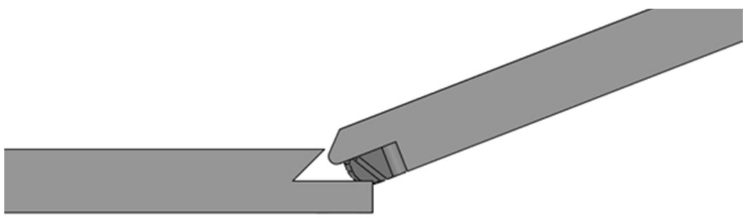


**Figure 3-12 Angling combination of dovetail joint**

### 3.1.2.1.2. Thickness of Flooring Joints

Structure of halving dovetail joints was simple in comparison with click joints, so it was possible to reduce thickness. In detail, click joint was modified tongue and groove joints. Click joint is composed of 3 protrusions (two of mortise and one of tenon) like Figures 3-13, 3-14, 3-15 and 3-16. Above all click joint, part what was combined was built only 1mm shoulder construction. This being so, due to complex structure of click joint, it could not be reduced thickness of floorings.

**Figure 3-13. Cross-sectional diagram of dovetail joints**

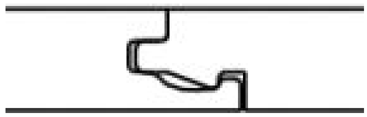


**Figure 3-14. Cross-sectional diagram of click joints**

**Figure 3-15. Outline of dovetail joint**

**Figure 3-16. Outline of click joint**

In comparison with click joint, dovetail joint was composed of 2 protrusions (one of tenon and one of mortise). Shape of dovetail was fixed tenon and mortise horizontally and vertically. So if thickness of dovetail flooring reduces, tensile strength cannot be affected. Figures 3-17, 3-18 and 3-19 are models of thinner dovetail joints.

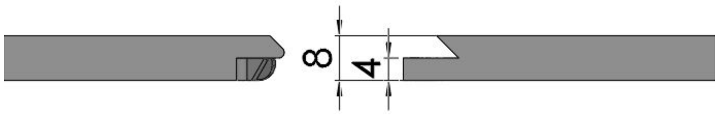



**Figure 3-17. Dimension of 8mm dovetail flooring of side view**

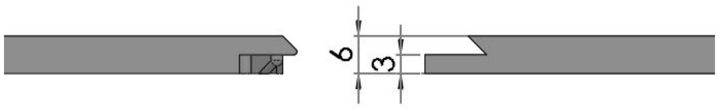



**Figure 3-18. Dimension of 6mm dovetail flooring of side view**

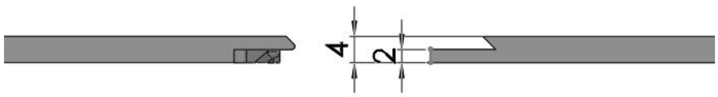



**Figure 3-19. Dimension of 4mm dovetail flooring of side view**

### 3.1.2.2. Computer Aided Manufacturing

In this paper, CAM program was Visualmill 5.0. Tool was used endmill. CAM was configured all of processing information. It was a radius 0.5mm and one flute reverse edge. The spindle speeds rotational was set up 18000rpm, and feed rate was 400mm/min. Flooring joint was manufactured rough machining and then finishing process. Machining tolerance was designated 0.1mm. After checking cutting simulation, G-code which was language of computer numerical control was converted to text file.

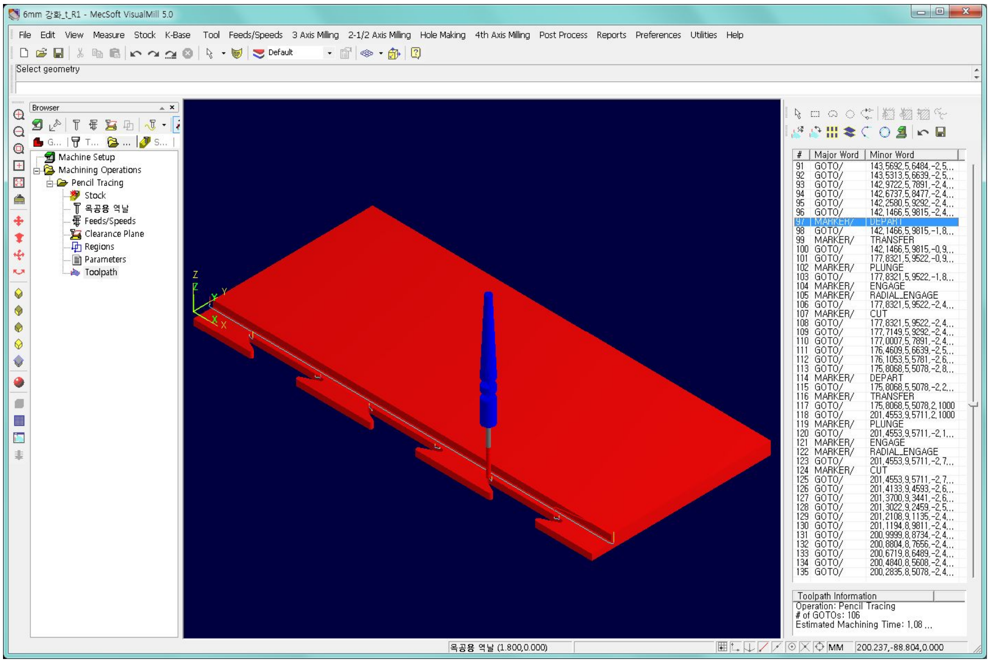



**Figure 3-20. Visualmill 5.0 program**

### 3.1.2.3. Computer Numerical Control

Dovetail joint of flooring was manufactured by computer numerical control. The program of CNC was Mach 3.0. G-code made from CAM process was imported Mach 3.0 and origin point of end-mill and flooring were corresponded. After setting parameters, CNC router was started and manufactured.


Figure 3-21. Monitor of Mach 3.0

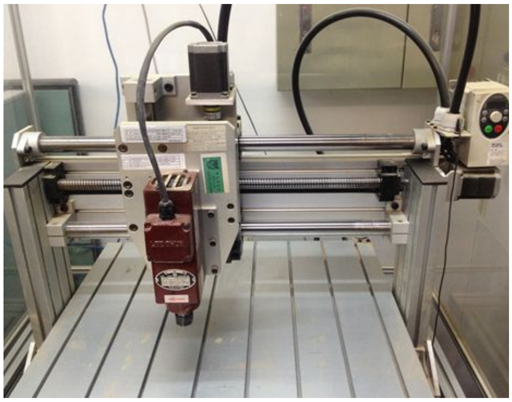


Figure 3-22. Triaxis CNC

### 3.1.3. Experiment method

#### 3.1.3.1. Heat performance simulation of floor heating

##### 3.1.3.1.1. Boundary condition

Heat transfers performance of flooring joints was simulated by transient thermal (ANSYS Workbench 14.5). Heating film was used as heat source and inputted 50℃. To reduce heat loss, insulation was set. Ambient temperature and the initial temperature of the material constant were 24℃.

### 3.1.3.1.2. Mesh

For thermal simulation, patch conforming meshing was used. It is a meshing technique in which all face and their boundary like edges and vertices within a very small tolerance are respected for a given part. This method was reflected geometry of joints like Figure 3-23.

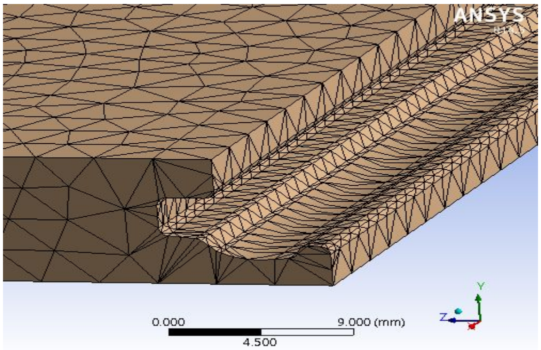



**Figure 3-23 Patch conforming meshed for the joins**

Tetrahedral mesh was used, and the total numbers of node and elements were given in Table 3-1. The dimension of elements was designated to 5mm.

**Table 3-1. Number of tetrahedral meshes for the floorings geometry**

| | No. of node | No. of elements |
|---|---|---|
| Tenon | 18571 | 10653 |
| Mortise | 20302 | 11862 |
| Groove | 30403 | 17526 |
| Tongue | 27485 | 15855 |
| Heating film | 1604 | 208 |
| Insulator | 1604 | 208 |

#### 3.1.3.1.3. Contact condition

Thermal simulation was focused on heat transfer at around flooring joints in this paper. To solve problem involving invisible contact area between two joints, one of the flooring was defined as the ‘target’ surface, and the other as the ‘contact’ surface. These two surfaces together were comprised as the ‘contact pair’. Contact elements were constrained against penetrating the target surface. However, target elements could penetrate through the contact surface. In consideration of heat transfer direction, the flooring model was designated contact or target in Table 3-2.

**Table 3-2. Contact condition**

| | contact | Target |
|---|---|---|
| Dovetail | Insulator | Heat film |
| | Floorings | Heat film |
| | Mortise | Tenon |
| Click | Insulator | Heat film |
| | Floorings | Heat film |
| | Tongue | Groove |

### 3.1.3.1.4. Material properties

At thermal performance simulation, required material properties were thermal conductivity, density and specific heat.

Thermal conductivity of wood was increased by temperature rise. The reason was that thermal conductivity of air in wood pore space was raised. Thermal conductivity of wood was directly proportional to absolute temperature. Kollmann (1951) was suggested relational expression.

$$K_2 = K_1\left\{1-\left(1.1-0.98S_o\frac{t_2-t_1}{100}\right)\right\}\ (kcal/m\cdot h\cdot ℃)$$

$t_1, t_2$ : Temperature

$K_1$ : Thermal conductivity of $t_1$

$K_2$ : Thermal conductivity of $t_2$

$S_0$ : Dry volume

Thermal conductivity of laminate flooring at 100℃ was acquired by experiment. Figure 3-24 shows relation between thermal conductivity and temperature by Kollmann’s formula.

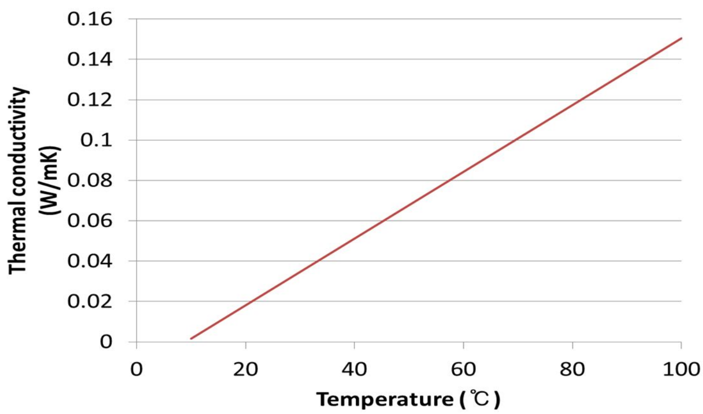



**Figure 3-24. Relation between thermal conductivity and temperature**

Material property of laminate floorings was given in Table 3-3. Density was measured at air dried condition.

Table 3-3. Material properties of laminate floorings

| | Density | Specific heat |
|---|---|---|
| | $kg/m^3$ | J/kg K |
| Laminate flooring | 891.54 | 1380 |

### 3.1.3.1.5. Heat source

Heat source which was used in simulation was assumed heat film. Temperature of heat film was obtained by preliminary experiment. Heat film was designated at 50℃ and measured by thermocouple. The temperatures were saved excel file at one second intervals in data logger, and the film was exported heat temperature in simulation.

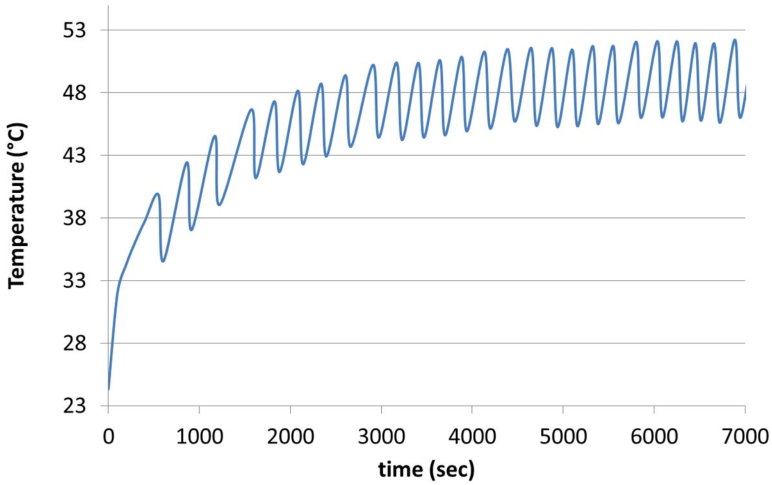



**Figure 3-25. Temperature of heat film**

### 3.1.3.2. Floor heating experiment

To compare to simulation, flooring heating test in a downscale heating system was experimented. Heating film was used heat source. The experiment was carried out at steady temperature and humidity room and the room temperature was maintained around 24 degree of Celsius. In order to prevent downward heat flux, insulator was installed under the heating film. Temperature of heat film was controlled to set up at 50 degrees of Celsius. Temperature of joints and surface of floorings were measured by thermo couples, as shown in Figure 3-26.

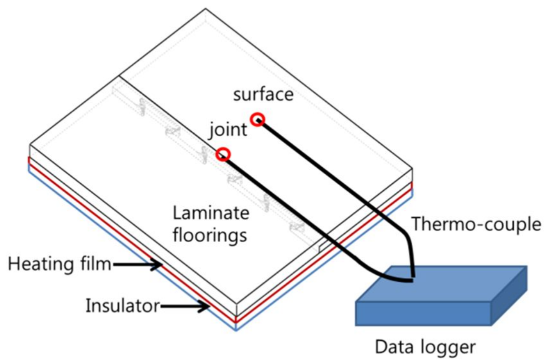



**Figure 3-26 Schema of floor heating experiment**

K-type thermocouple was attached to two points, joint and surface flooring and measured the temperatures of the points until reaching steady state. The temperatures were saved at one second intervals in data logger.

### 3.1.3.3. Binding force of joints

Joint of flooring was tested binding force using Universal testing machine like Figure 3-27. Test speed was set up 3mm/min. Pre-load was designated 1N. Size of specimen was Figure 3-28. As of one tenon, width of joint was 60mm, and gauge length was 110mm. Due to same structure of click joint anywhere, position of specimen was affected. Repetition number was 4 times.

**Figure 3-27. Binding force of joints of Universal testing machine**

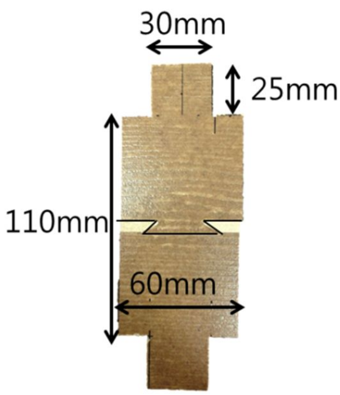



**Figure 3-28. Size of specimens of binding force**

# 4. Results and Discussion

## 4.1. Heat performance simulation of flooring heating

### 4.1.1. Dovetail joint of flooring

Figure 4-1 showed temperature of dovetail joint of flooring. Time of steady state was from 5000 sec, and temperature was averaged after 5000 sec. Surface temperature of dovetail flooring was 41.5℃ and dovetail joint temperature was 40.7℃. Surface temperature was 0.8℃ higher than joint temperature. The reason was that heat was outflow through a gap of joint. Figure 4-2 showed temperature distribution of surface floorings.

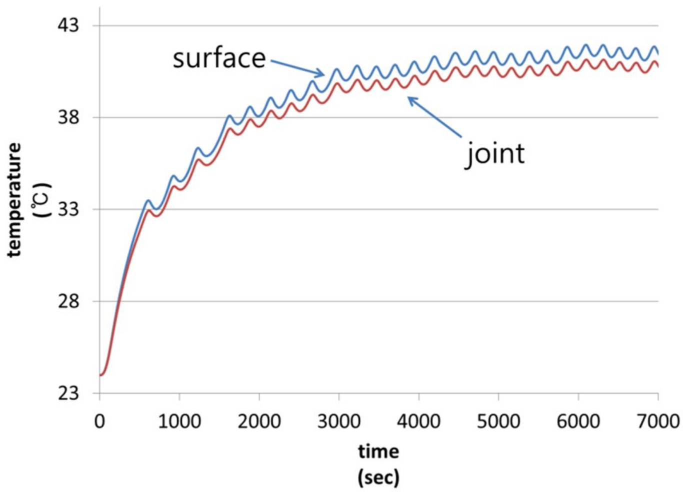



**Figure 4-1. Temperature of dovetail joint of flooring in simulation**

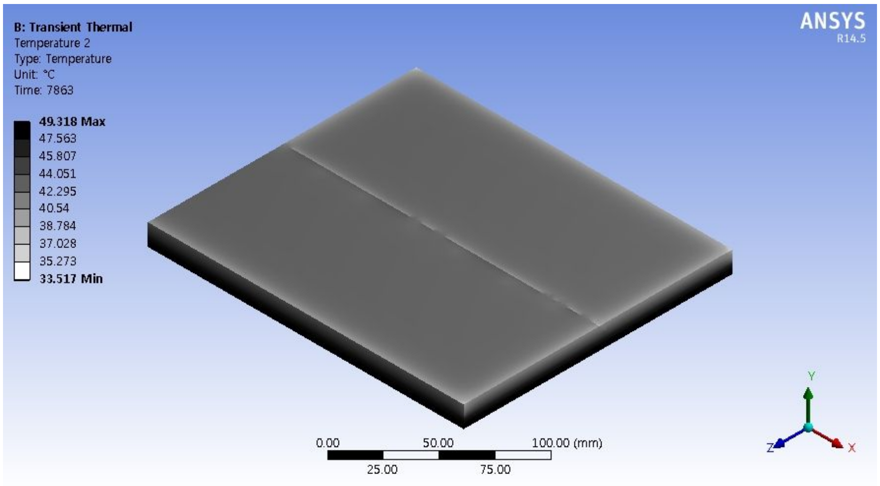



**Figure 4-2. Surface temperature distribution of dovetail joint**

### 4.1.2. Click joint of flooring

Results of click joint simulation were different phenomenon. Figure 4-3 showed temperature of dovetail joint of flooring. Temperature of click joint also was averaged after 5000 sec. In click flooring, surface temperature was 40.6℃ and joint temperature was 36.5℃. Surface temperature was 4.1℃ higher than joint temperature.

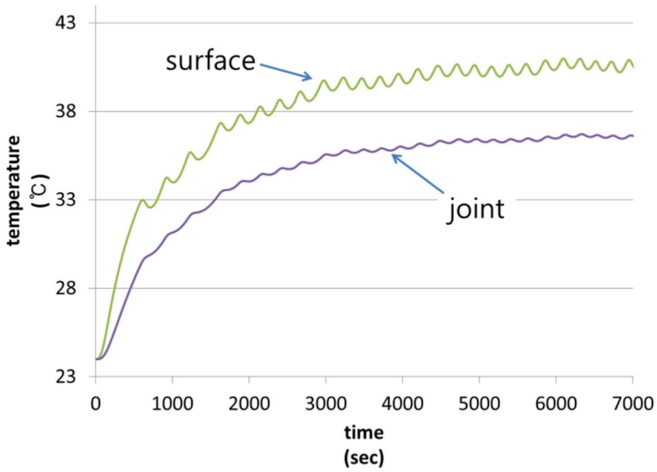



**Figure 4-3. Temperature of click joint of flooring in simulation**

Temperature distribution of click joint was like Figure 4-4. There was a big temperature difference between joint and surface at click floorings.

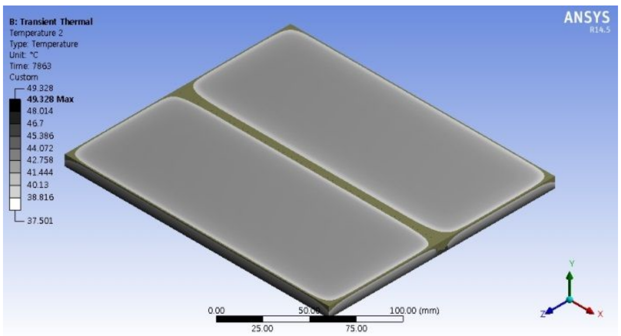



**Figure 4-4. Surface temperature distribution of click joint**

### 4.1.3. Analysis of heat transfer of joints

As results of simulation, temperature of joints was quite different. Click joint temperature was 4.2℃ lower than dovetail joint, and surface temperature of click was 0.9℃ lower than dovetail. Figure 4-5 demonstrated why temperature of dovetail joints was high. There were empty spaces between dovetail joints because every edge of dovetail joint was cut rounding. The air of lower side area was heated fast and moved upper side. The heated air was blocked at joint so it was performed keeping warmth. On the contrary, click joints was penetrated in a straight line parallel to horizontal line of floor. In that case, heated air from heat film was leaked along the joins it occurred heat loss more than dovetail joint.

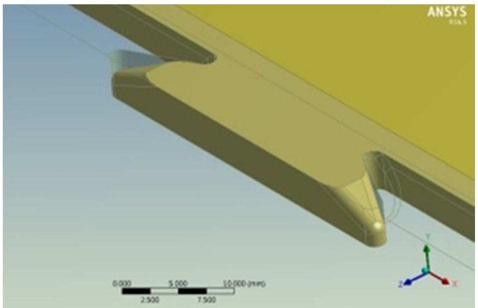



**Figure 4-5. Illustrating upper side view of empty spaces of dovetail joint**

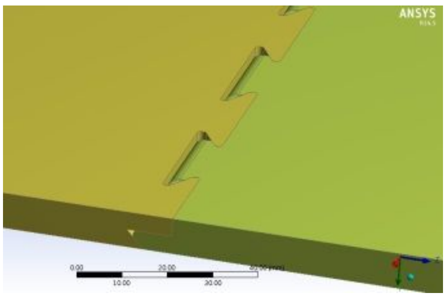



**Figure 4-6. Illustrating lower side view of empty spaces of dovetail joint**

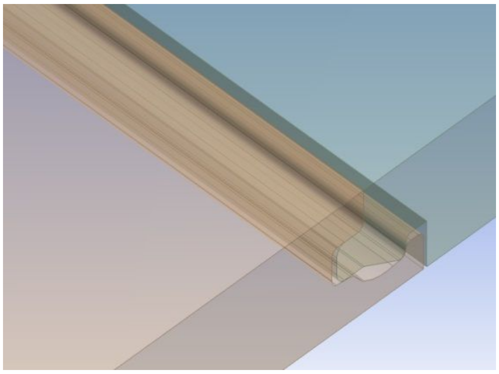


**Figure 4-7. Illustrating empty spaces of click joint**

Figures 4-8 and 4-9 were a cutting section from Z axis. Figure 4-9 shows that surface temperature of click flooring was low relatively because heat was not transferred at joint space which was penetrated in a straight line parallel to horizontal line.

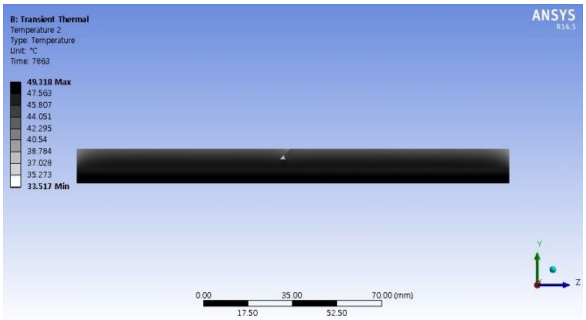



**Figure 4-8. Cutting section of temperature distribution of dovetail joint**

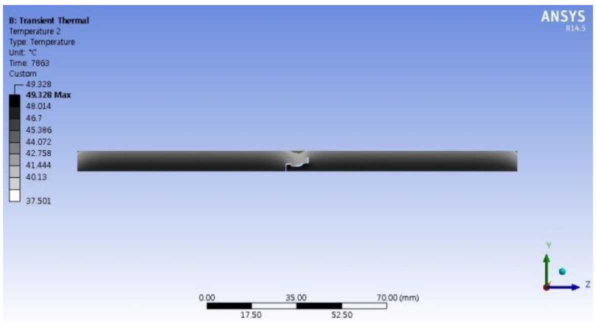



**Figure 4-9. Cutting section of temperature distribution of click joint**

## 4.2. Floor heating experiment

In experiment, temperature of dovetail joint was 38.0℃ and the surface temperature of dovetail flooring was 38.7℃. Surface temperature of click flooring was 38.1℃ and temperature of click joint was 37.3℃. Temperature of dovetail joint was 0.73℃ higher than temperature of click joint and surface temperature of dovetail flooring was 0.6℃ higher than it of click flooring.

Temperature difference of dovetail flooring between surface and joint was similar to simulation. At click flooring, temperature of joint was the lowest both of simulation and floor heating experiment. However, in case of experiment, temperature difference was 0.6℃, it was smaller than simulation. The reason was that heat transfer of simulation at empty space was not conducted. On the contrary to simulation, heat transfer of experiment at empty space was affected by hot air.

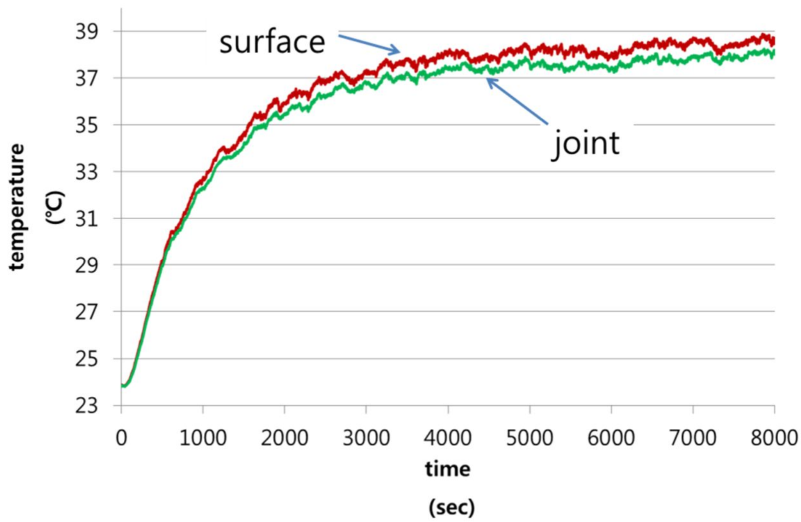



**Figure 4-10. Temperature of dovetail joint of flooring by thermocouple**

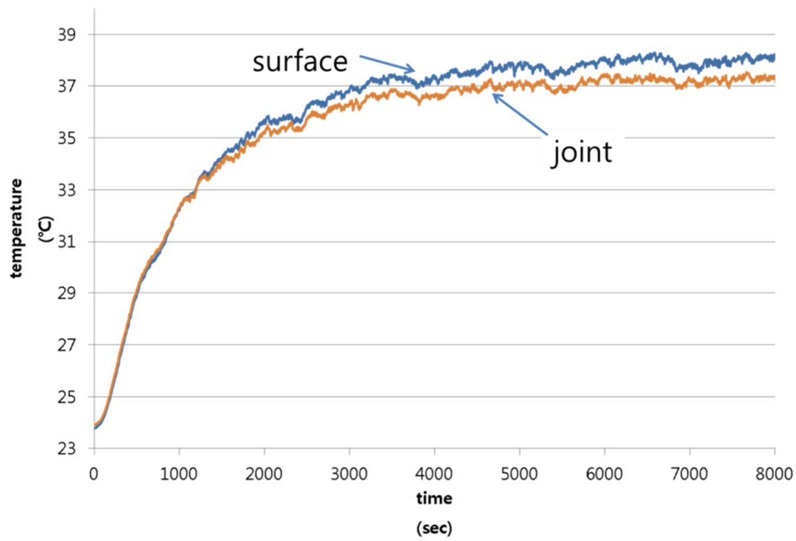



**Figure 4-11. Temperature of click joint of flooring by thermocouple**

Table 4-1 was temperature of infrared camera by time. Figures 4-12 and 4-13 were temperature distribution of infrared camera by time. Temperature infrared image also was similar to thermocouple. Temperature of dovetail flooring was higher than click flooring. In comparison with thermocouple, temperature of infrared camera was about 1℃ higher than thermocouple.

**Table 4-1. Temperature of infrared camera by time**

| | Dovetail flooring temp. (℃) | | Click flooring temp. (℃) | |
|---|---|---|---|---|
| time | surface | joint | surface | joint |
| 0 min | 25 | 25 | 25 | 25 |
| 10 min | 31 | 30 | 29 | 29 |
| 20 min | 35 | 35 | 35 | 34 |
| 30 min | 37 | 37 | 36 | 35 |
| 40 min | 38 | 38 | 38 | 37 |
| 50 min | 41 | 40 | 39 | 38 |
| 60 min | 41 | 40 | 39 | 38 |

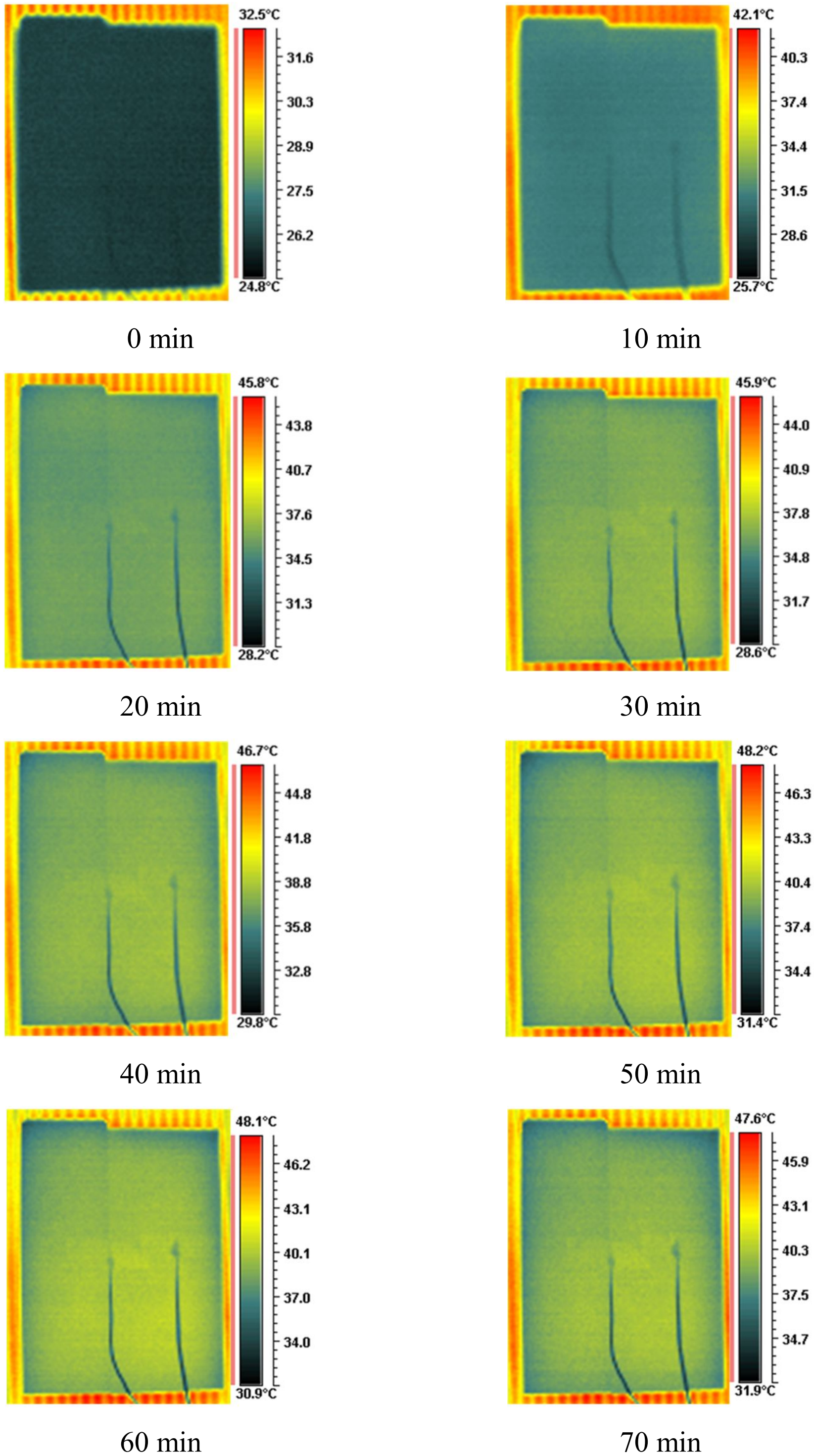



**Figure 4-12. Images of dovetail floorings of IR camera by time**

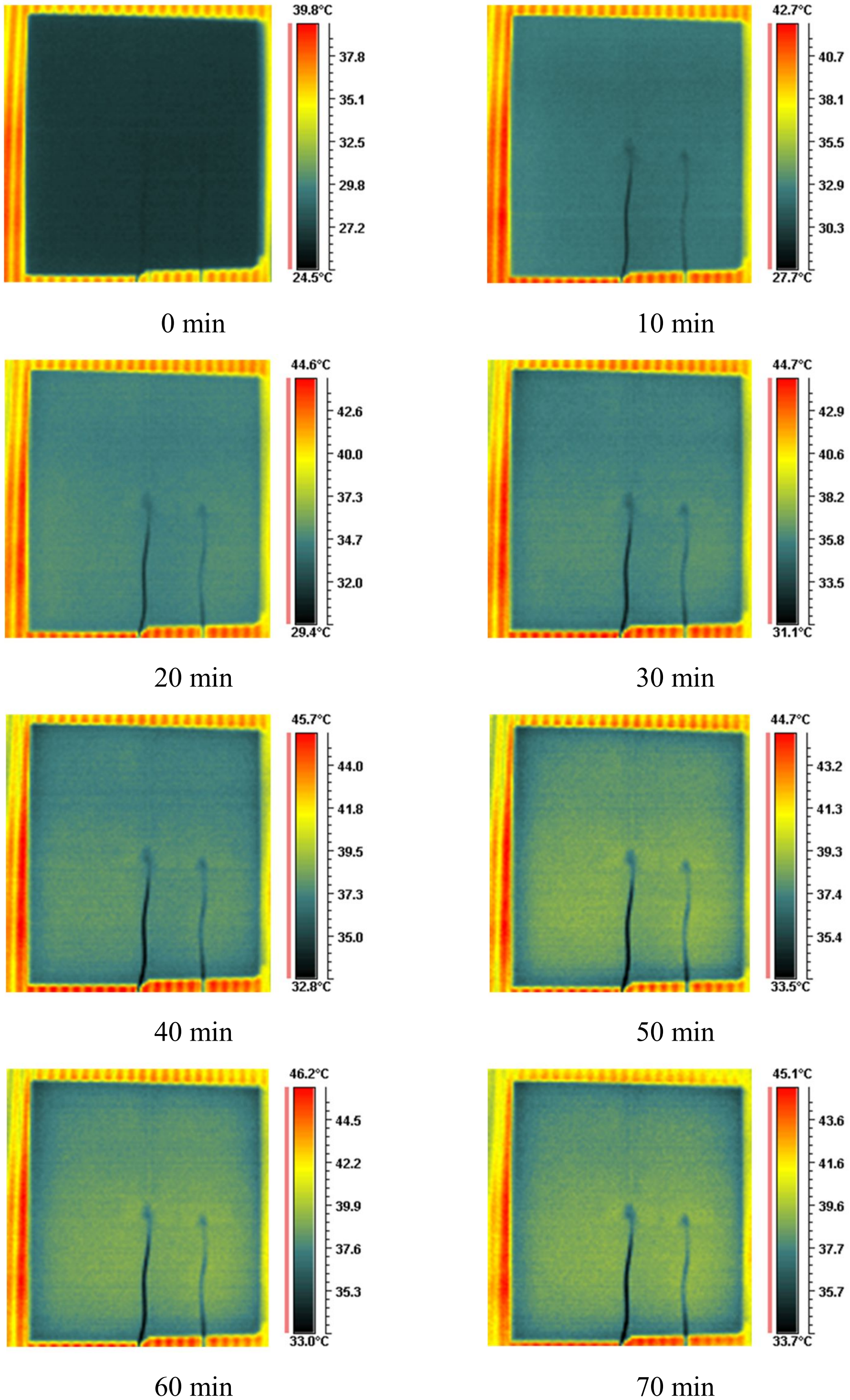



**Figure 4-13. Images of click floorings of IR camera by time**

## 4.3. Binding force of joints

Figures 4-14 and 4-15 were demonstrated that binding force of dovetail joints was stronger than click joints. One dovetail joint was based on standard. Binding force of 8mm dovetail joint was measured 335N and it was the largest binding force. Binding force of click joint was 230N and it was 105N lower than dovetail joint. Figure 4-15 shows binding force of dovetail by thickness. Binding force of 6mm dovetail joint was 194N and it was similar to binding force click joint.

Backer layer was made high-press laminate. It was enhance strength and prevented moisture from sub-floor. For making thickness of 6mm and 4mm, baker layer was planned. If 4mm and 6mm dovetail flooring are manufactured with backer layer, tensile strength of 4mm and 6mm will be increased like 8mm.

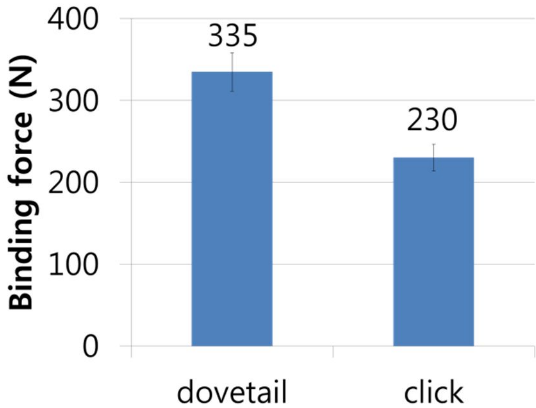



**Figure 4-14. Binding force of dovetail and click joint**

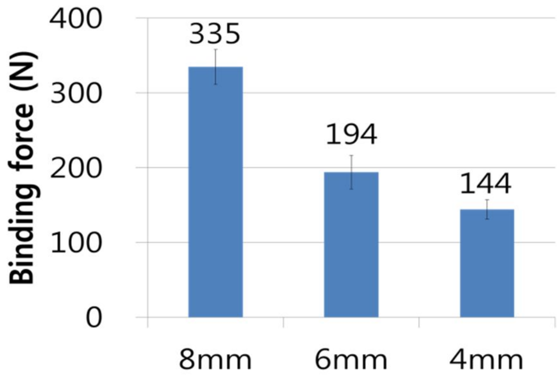



**Figure 4-15. Binding force of dovetail joint**

Failure shapes were like Figures 4-16, 4-17, 4-18 and 4-16. One side of dovetail tenon was failure and then dovetail mortise was failure. In case of click joint, shoulder construction part was only 1mm. Click joint was fallen out tongue and groove easily even though end piece of click shoulder construction was broken.

**Figure 4-16. Failure shape of 8mm dovetail joint**

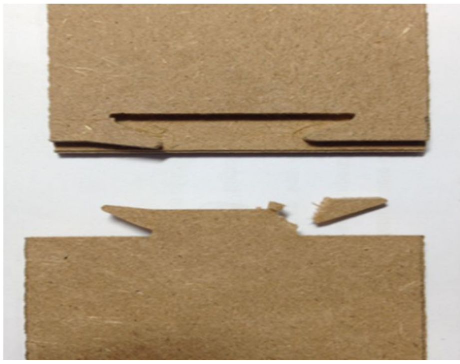


**Figure 4-17. Failure shape of 6mm dovetail joint**

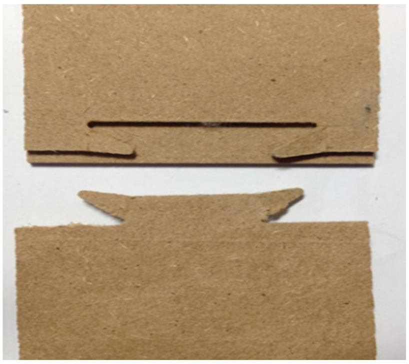


**Figure 4-18. Failure shape of 4mm dovetail joint**

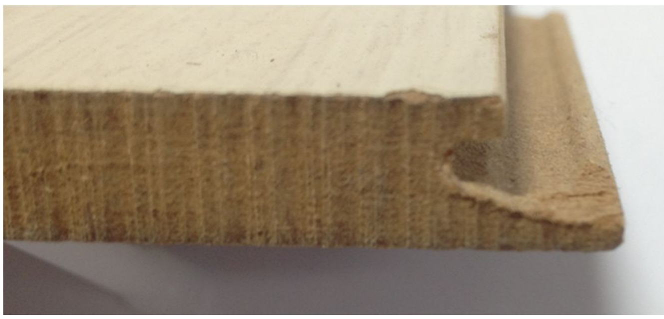


**Figure 4-19. Failure shape of click joint**

# 5. Conclusions

The final conclusions of this study are as follows.

1. To enhance heat performance, new joint which was applied dovetail joint was designed. For considering design and preventing to expose the dovetail patterns upper surface of flooring, the joint was constructed with half dovetail type. The dovetail joint was designed connect at apart 4mm from the bottom. And upper side was designed to form shape of oblique line to prevent falling out floorings upwards. To assembly easily, every edge of dovetail joint was cut rounding.

2. Heat performance of joints was evaluated by computer aided engineering. In heat transfer simulation, the two different joints which were dovetail and click were resulted in similar average surface temperature, but joint temperatures were different. The temperature of dovetail joint was 40.7℃ and click joint was 36.5℃, dovetail joint was higher than click joint. The surface temperatures of dovetail floorings and click floorings were 41.5℃ and 40.65℃ respectively, surface temperature of dovetail flooring was higher than click flooring. As results, to change joint structure reduced heat loss.

3. Temperature of experiment was similar tendency to heat transfer simulation. By measured thermocouple, the temperature of dovetail joint was 38℃ and temperature of click joint was 37℃, temperature of dovetail joint was higher than temperature of click joint. The surface temperature of dovetail and click flooring was 38℃. Temperature infrared image also was similar to thermocouple. Temperature of dovetail flooring was higher than click flooring.

4. Binding force of dovetail was higher than click joint. In case of dovetail, dovetail joint was stronger binding force, even though thickness of 4mm and 6mm dovetail joints were thicker than 8mm click joint. If 4mm and 6mm dovetail flooring are manufactured with backer layer, tensile strength of 4mm and 6mm will

be increased like 8mm. By dovetail joint, thickness of floor could be reduce. This, also, could lead to decrease manufacturing coat and product price as well as reducing heating time.

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# 초 록

생활의 질이 향상되고 환경 친화적인 제품을 추구하게 되면서 주거공간 중 인체와 가장 많이 접촉하는 바닥재에 대한 관심이 증대되고 있다. 목재는 아름다운 무늬와 뛰어난 흡음성으로 각광받고 있는 바닥 재료이다. 제재목은 표면강도 및 수분변화에 따른 뒤틀림, 할렬 등의 변형문제와 낮은 열전도계수로 인한 난방문제로 인해 가정에서 사용하기 부적절하다. 이러한 단점을 보완한 강화마루가 개발되었고 현재까지도 강화마루의 수요가 증가하고 있다. 1990 년대 초 유럽에서 개발된 클릭형 접합부는 비접착 결합방식으로 시공의 편의성에 따른 시공, 보수비가 적게 들며 재사용이 가능한 장점을 가진다. 그러나 한국의 바닥 난방조건에서 사용 시 난방열에 의한 바닥재의 건조로 수축하여 접합부에서 틈새가 발생하고 결합이 약해지며, 또한 접합부를 소형화 또는 박막화시키지 못 하여 열전달 경로가 증가하여 바닥 난방 속도가 감소하는 단점을 가진다.

본 연구에서는 전통접합부 중에서 자체 결합력이 강한 주먹장 접합부를 응용하여 비접착식 바닥재 접합부를 개발하였다. 주먹장 접합부의 표면에 틈새 면적을 줄이고, 디자인 면을 고려하여 주먹장부가 바닥재 표면 위로 노출되는 것을 막기 위해 반턱맞춤으로 설계하였다. 두께 8mm 바닥재에서 4mm 는 주먹장으로 설정하고 남은 상부 4mm 는 변형에 의한 바닥재의 빠짐 현상을 방지하기 위하여 45℃의 경사각으로 사선 처리하였다. 부드러운 경사 결합을 위해 주먹장 장부의 모서리를 라운딩처리 하였다. 클릭형 접합부는 제혀쪽매에서 변형된 형태로 3 층으로 구성되어 있다. 3 층 중에서도 결합을 유지하는 부분은 아래쪽의 1mm 의 돌출된 걸림구조로 두께를 줄이게 될 경우 결합력에 크게 영향을 미친다. 주먹장 접합부는 크게 2 층으로 구성되어 있고, 주먹장의

형상이 바닥재의 수평과 수직으로 결합하기 때문에 바닥재의 두께를 반으로 줄여도 결합 구조를 유지할 수 있다.

컴퓨터 이용 공학(Computer Aided Engineering, CAE)을 활용하여 접합부의 열전달 성능을 분석하였다. 접합부의 형상은 복잡하고 다양하여 직접 분석하는데 한계가 있기 때문에 CAE 를 통하여 접합부의 설계에서부터 성능을 미리 예측 할 수 있었다. 열전달 시뮬레이션을 통하여 바닥온도가 50℃인 열원으로 난방을 한 경우 바닥이 정상상태에 도달했을 때 주먹장 바닥재의 표면온도는 41.5℃이고, 접합부 온도는 40.7℃로 표면보다 접합부의 온도가 0.8℃ 낮았다. 클릭형 바닥재의 표면온도는 40.6℃이고, 접합부 온도는 36.5℃로 4.1℃의 차이로 주먹장 접합부보다 온도가 낮을 뿐만 아니라 표면과 접합부의 온도차이도 크게 나타났다. 주먹장 바닥재는 클릭형 바닥재보다 모든 포인트에서의 온도가 더 높았다. 그 이유는 주먹장 접합부의 바닥면 빈 공간의 열은 빠르게 데워지고 상부 빈 공간에 갇히게 되면서 데워진 열이 보온 역할을 하는 반면, 클릭형 접합부의 빈 공간은 통로처럼 길게 연결되어 있어 바닥에서 데워진 뜨거운 공기가 세어나가 열 손실이 크기 때문이다. 바닥난방실험에서, 열전대로 측정한 주먹장 접합부의 온도는 38℃이고 클릭형 접합부의 온도는 37℃로 주먹장 접합부의 온도가 더 높았다. 시간에 따른 IR 카메라로 측정한 온도에서도 주먹장 접합부의 온도가 클릭형 접합부보다 더 높았다.

인장강도 실험에서 주먹장 접합부 인장강도가 클릭형 접합부 인장강도보다 높은 값을 보였다. 4mm 와 6mm 의 주먹장 접합부는 8mm 의 클릭형 접합부보다 더 높은 인장강도 값을 얻었다. 실제 바닥재로 생산될 경우 4mm 와 6mm 의 바닥재에도 HPL (High Press Laminate)의 바닥층으로 만들게 되면 8mm 주먹장 접합부와 비슷한 인장강도를 나타날 것으로 사료된다. 이처럼 주먹장 접합부를 강화마루 접합부에 적용하면 더 얇은 바닥재를 생산 할 수 있다. 바닥재가 더

얇게 되면 바닥난방 속도를 향상 시킬 뿐만 아니라 재료비 절감 효과도 기대할 수 있다.

**주요어: 목질 마루 바닥재, 강화마루, 주먹장 접합부, 클릭형 접합부, 바닥난방, Computer Aided Engineering**

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