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# Deflection Characteristics and Heat Transfer of Plywood for Wood–based Flooring by Cross–band Veneer Composition

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Since the 1990s, there has been an increased customer demand for plywood flooring in Korea. The raw material and production costs have increased because of the changed environment of the industry. The tropical timber used as raw flooring material, such as Red Meranti (Shorea acuminate), has been depleted. In addition, countries in Southeast Asia have changed the species used in afforestation. As a result, it has become harder to secure good quality raw materials for plywood. Moreover, plywood prices increased suddenly after the earthquake in Japan. In China, Eucalyptus (Eucalyptus globulus) has been used as a raw material as a countermeasure to the changed environment of the industry. In this study, the possibility of using flooring consisting of a Eucalyptus veneer in cross–bands was examined using several experiments. Flooring consisting of Red Meranti was used for comparison. Two factors were found to have an impact on the deflection and heat transfer: the type of density gradient and the density difference between a long–grain veneer and short–grain veneer.

**Key words**: deflection, density gradient, flooring, plywood, thermal conductivityt

## INTRODUCTION

The essential qualities needed for a floor heating system can be classified into three requirements. The first is structural durability to prevent deformation by an ondol, which is a Korean floor heating system. The second and third are surface durability and the heat transfer efficiency of the heating system. In particular, the deformation and heat transfer efficiency of the heating system are significant factors for flooring.

The main factor affecting these two requirements is the plywood used for the flooring material. Two problems can be found on the basis of the quality or grade of the plywood. Therefore, flooring manufacturers are keeping a close watch on the plywood supply and demand. Many flooring manufacturers import plywood from Southeast Asia. The plywood used in the domestic market is categorized as imports from Southeast Asia such as Indonesia and Malaysia and others produced using imported wood veneers.

The energy used in construction and operation constitutes over 50% of the world's total energy use. Moreover, there have been increases in the insecurity over the energy supply and the attention given to climatic change conventions and global environmental problems. Hence, there is an increased need for energy saving and emphasis needs to be placed on the construction of energy efficient buildings (Kim S.D. *et al*., 2010). Although there are many energy saving factors in a building, giving attention to the thermal conductivity of the material used is a basic way to reduce energy consumption. Culturally, radiation heating systems have commonly been used, with the ondol as a typical example in Korea (Kang S. G. *et al*., 2011).

Heating and cooling energy account for 59.1% of the total energy consumption in a residence, according to a survey by the Korea Energy Management Corporation. If the energy efficiency of the radiation heating system is improved, the heating and cooling energy consumption will be decreased. Furthermore, this will have the effect of reducing the total energy consumption in a building. However, there is a tendency to use low thermal conductivity flooring in the industrial world, which will have a damaging effect on the energy efficiency of a radiation heating system (Kim S.D. *et al*., 2010)

The purpose of this study was to investigate the correlation between the deformation or thermal conductivity and the density of a cross–band veneer. An additional purpose of this study was to create a high thermal conductivity material by improving the energy efficiency of flooring.

## MATERIALS AND METHODS

### Test materials

*Plywood for Flooring*

Two types of cross–bands, with different species, were used in this study. The cross–band veneers were made from Eucalyptus and Red Meranti. The Eucalyptus veneer for the cross–bands was bonded using melamine urea formaldehyde adhesive (MUF), while the other was bonded using phenol formaldehyde adhesive (PF). The dimensions of plywood were 1,220 (W) × 2,440 (L) × 7.2 (T) mm. The detailed specifications of the layer compositions are shown in Table 1.

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**Table 1.** Specification of Plywood

| Layer of veneer | Sample 1 [Species/ thickness (mm)] | | Sample2 [Species/ thickness (mm)] | |
|---|---|---|---|---|
| Long G. (Face) | | 1.3 | Red Meranti | 1.1 |
| Short G. (Cross Band) | | 2.1 | Eucalyptus | 2.1 |
| Long G. (Core) | Red Meranti | 1.3 | Red Meranti | 1.6 |
| Short G. (Cross Band) | | 2.1 | Eucalyptus | 2.1 |
| Long G. (Back) | | 1.3 | Red Meranti | 1.1 |

* The thickness of each veneer is based on composition thickness. Finally, It made on 7.2 mm~7.5 mm after hot/cold pressing and sanding process.

*High pressure melamine laminate sheet*

In Korea, high–pressure melamine laminate sheets (HPM) are used as flooring surface materials over a substrate made of particle board or plywood.

These sheets are laminated with a melamine resin impregnated overlaid paper to achieve a wear resistant surface, along with a melamine resin impregnated printed paper and phenolic resin impregnated Kraft paper. After the lamination process, a hot and cold press process is conducted under high–temperature (170°C) and high–pressure (50 kgf/cm$^2$) conditions for 90 min. The HPL and plywood lamination process employs adhesives and cold pressing. In this case, the adhesive used was a moisture–curable polyurethane adhesive with a solid content of 60%. PVA (polyvinyl alcohol) was a major component of the adhesive and the hardener was an isocyanate component. The major component and hardener were mixed at a 9:1 by weight. The amount of spread was 140 g/m$^2$. The press cycle utilized a pressure of 10 kgf/cm$^2$ for 1 h, and it was cured for 24 h at room temperature.

## Test methods

*Manufacture of Flooring*

The flooring manufacturing process is shown in Figure 1. It involved pressing, back groove processing, and tongue and groove processing in that order. The size of the final sample was 90 × 800 × 7.5 mm.

*Test of properties*

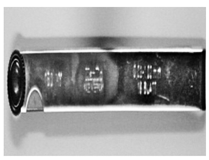
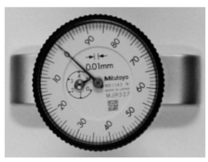
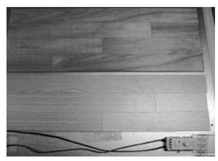
First, to calculate the density gradient in the thickness direction of a sample, a DAX5000 from Grecon (Germany) was used. The sample size for this test was 50 × 50 mm. In addition, the moisture content was tested to acquire data on the warping of the flooring. The parameters of the test were the temperature and relative humidity to simulate the summer and winter seasons.

Two conditions were used to measure the warping of the flooring between the summer and winter. The first was a high temperature (under 80°C) and dry condition for the winter. The temperature and humidity conditions for the summer included a temperature under 35°C, relative humidity of 75%, and equilibrium moisture con-

a) Resin Spreader b) Cold Pressing c) Calibration d) Back Grooving e) Gang-lip Saw e) Tongue&Grooving

**Fig. 1.** Process of flooring manufacturing.

**Table 2.** The list of test

| Test Item | Density Profile | To measure Linear expansion/ shrinkage according to the time elapsed and warp in length direction | The test of deformation on heating panel (Size of heating panel is 850×850 mm, set up temp. is 45°C) | | |
|---|---|---|---|---|---|
| | | | Gap on the floor | Height difference | Heat transfer on heating panel |
| Method | It was used with DAX5000 of Grecon (Germany). Sample size for test is 50×50×10 mm.   | To measure warping of flooring in summer and winter condition. 1) High temperature and dry condition (80°C) 2) High temperature and humidity condition (35°C, relative humidity 75%, equilibrium moisture content 14%. | Using the thickness gauge to check gap on the floor. (Thickness Gauge, Mitsutoyo)  | Using the depth gauge to check Height difference on the floor (depth Gauge, Mitsutoyo)  | 1) Arrival time to target temp. (45°C) 2) Maximum temp. FLUKE ; Hydra series2  |

tent of 14%.

As mentioned above, a deformation experiment on a heating panel was carried out by heating the panel to verify the deformation results of floor heating. The size of the heating panel was 850 × 850 mm. In this experiment, the temperature was set to 45°C using a temperature controller. The deformation variables for the heating panel were the height difference and gaps in the floor. A thickness gauge was used to measure the height difference in the floor, while a depth gauge was used to measure the floor gaps. The test interval was 8 h.

In order to calculate the surface temperature of samples on the heating panel, the temperature of the heating panel was set at 45°C and it was covered to maintain the same condition as the test. A FLUKE Hydra series2 was used for this test and the interval was 8 h. The variables in this experiment were the arrival time at the target temperature (45°C) and the maximum temperature.

## RESULTS AND DISCUSSIONS

### Density Profile

In the density profile results, the Red Meranti samples had a higher average adhesive density than the

**Table 3.** Density analysis

| Type of processing | Species of cross bands layer | Average density of adhesive layer ($kg/m^3$) | Average density difference of close two layers ($kg/m^3$) |
|---|---|---|---|
| Plywood | Red Meranti | 1,322 | 176.3 |
| | Eucalyptus | 898 | 305.3 |
| Flooring | Red Meranti | 1,379 | 177.3 |
| | Eucalyptus | 1,024 | 304.6 |

**Table 4.** Density profile of sample

| Species of cross bands layer | Density Profile | | Type of density gradient |
|---|---|---|---|
| Red Meranti | Face | 350 | M type |
| | Short grain core | 520 | |
| | Long grain core | 360 | |
| | Short grain core | 540 | |
| | Back | 370 | |
| Eucalyptus | Face | 560 | W type |
| | Short grain core | 310 | |
| | Long grain core | 700 | |
| | Short grain core | 330 | |
| | Back | 580 | |

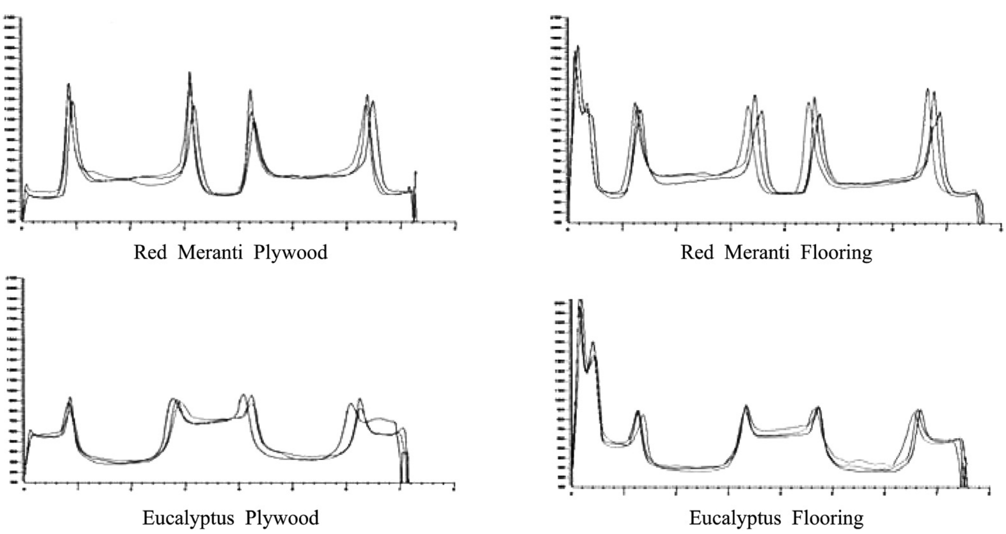



**Fig. 2.** Density Profile of Red Meranti and Eucalyptus sample.

Eucalyptus samples. By contrast, the Eucalyptus samples had a higher average gap layer density. There were two types of densities based on the density gradient and veneer composition. The first was the M type, which meant the cross–bands had a higher density than the other layers, and the other was the W type, which meant the cross–bands had a lower density than the other layers.

**Warping on different condition**

*High Temperature & Dry condition (Winter condition)*

A linear shrinkage phenomenon occurred under this condition, where the plywood samples had a higher change in length than other flooring samples such as those in Fig. 3. Because of the HPM layer, the flooring samples had different internal stress values, which prevented a change in length. Therefore, the flooring processing improved the change in length. The plywood samples that had Eucalyptus cross–bands had four times the linear shrinkage of the plywood samples that had Red Meranti cross–bands. This was because the Eucalyptus samples had a higher average density difference between two close layers than the Red Meranti samples, as shown in Table 3.

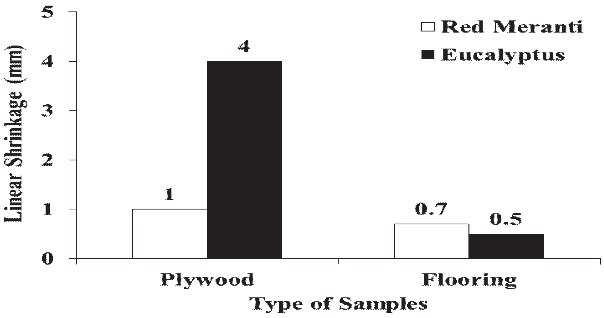



**Fig. 3.** Result of Linear shrinkage test under dry condition at high temperature.

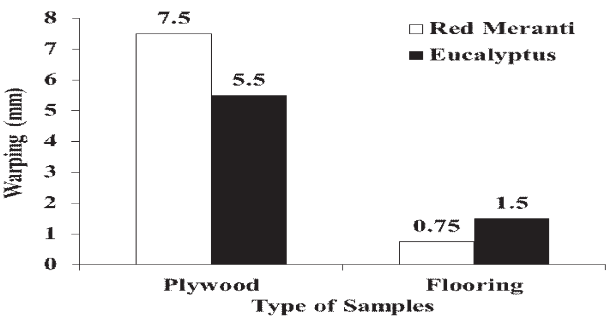



**Fig. 4.** Result of warping test under dry condition at high temperature.

*High Temperature & Humidity Condition (Summer condition)*

A linear expansion phenomenon occurred under this condition, as shown in Fig. 5. The flooring processing improved the linear expansion by the same logic as used for the summer condition of the HPM layer. Unlike the winter condition, the hydrophilic property was considered to affect the linear expansion and warping. Samples with Red Meranti cross–bands and flooring samples had a greater hydrophilic property than the comparison samples.

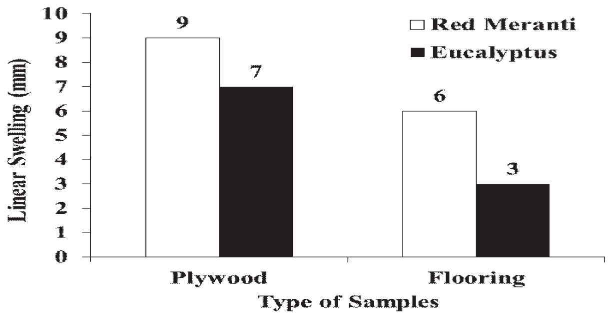



**Fig. 5.** Linear expansion under high temperature & humidity condition.

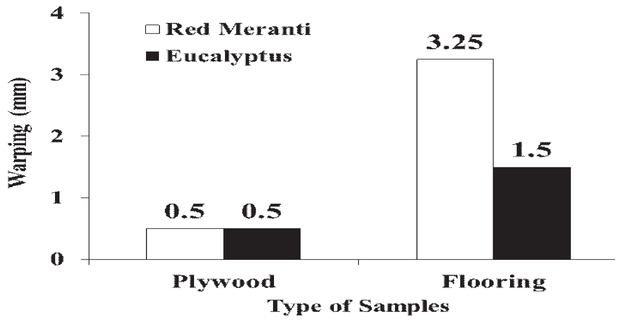



**Fig. 6.** Warping change under high temperature & humidity condition.

*Deformation on heating panel*

Double–sided adhesive tape (3M) was used to glue samples equally on the heating panel. Flooring samples and samples with Red Meranti cross–bands had smaller floor gaps.

Samples with Eucalyptus cross–bands had larger height differences than the Red Meranti cross–band samples.

Flooring processing did not improve the height difference for the floor because of the stress difference between the HPM and double–sided adhesive tape. The stress of the HPM layer was larger than the stress of the double–sided adhesive tape. Hence, the flooring samples had a larger height difference on the floor.

*Heat transfer on heating panel*

The purpose of the heat transfer experiment was to measure the energy efficiency under a real heating condition. The Red Meranti samples not only had a shorter arrival time to the target temperature but also reached a higher maximum temperature than the Eucalyptus samples. Flooring specimens arrived at a higher maximum temperature because of the flooring process. The density analysis results showed that the Red Meranti samples had a higher mean density. Therefore, their conductivity was higher than the Eucalyptus samples. The density of the cross–bands, which was almost 60% of the thickness, was considered to be a main factor in the heat transfer for the flooring.

## CONCLUSION

1. Two factors were found to impact the deformation: the type of density gradient and the density difference between a long–grain veneer and short–grain

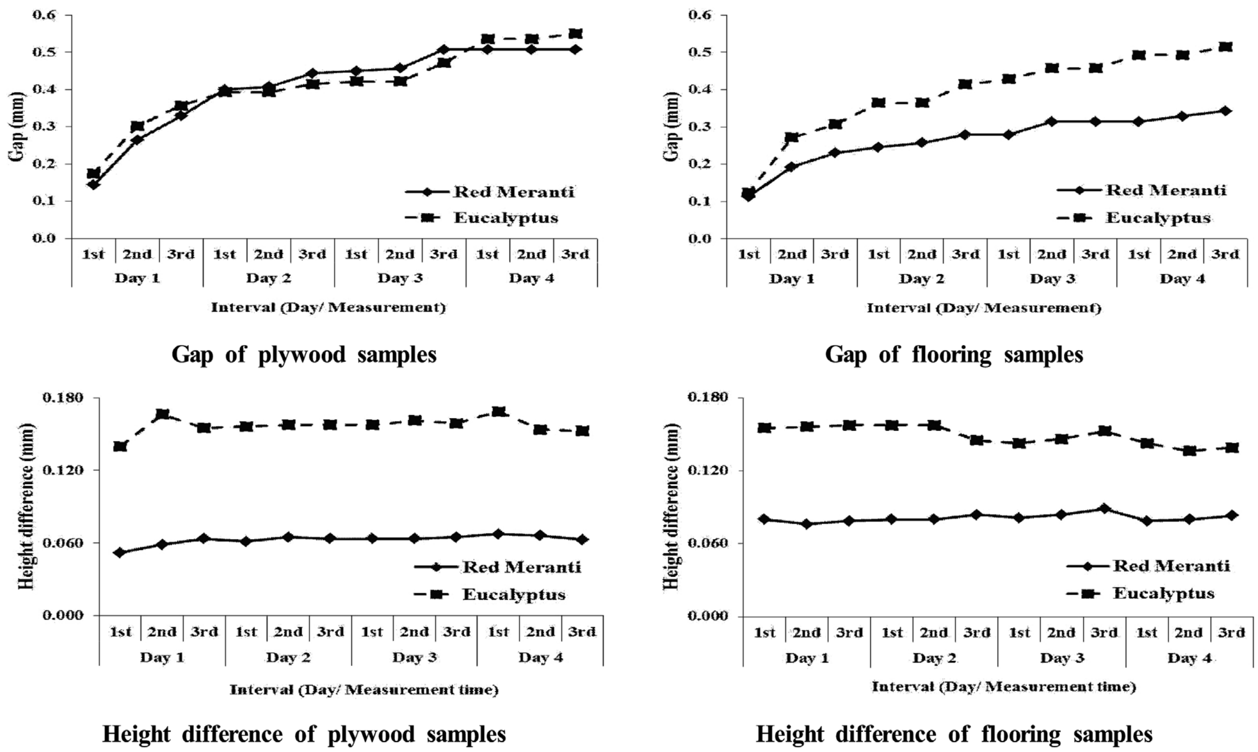



**Fig. 7.** Deformation of Red Meranti & Eucalyptus sample on heating panel.

**Table 5.** Heat Transfer Properties on Heating Panel

| Processing Type | Species of Cross-bands Layer | Arrival Time to Target Temperature (min) | Maximum Temperature (˚C) |
|---|---|---|---|
| Plywood | Red Meranti | 29 | 94 |
| | Eucalyptus | 44 | 89 |
| Flooring | Red Meranti | 29 | 99 |
| | Eucalyptus | 40 | 90 |

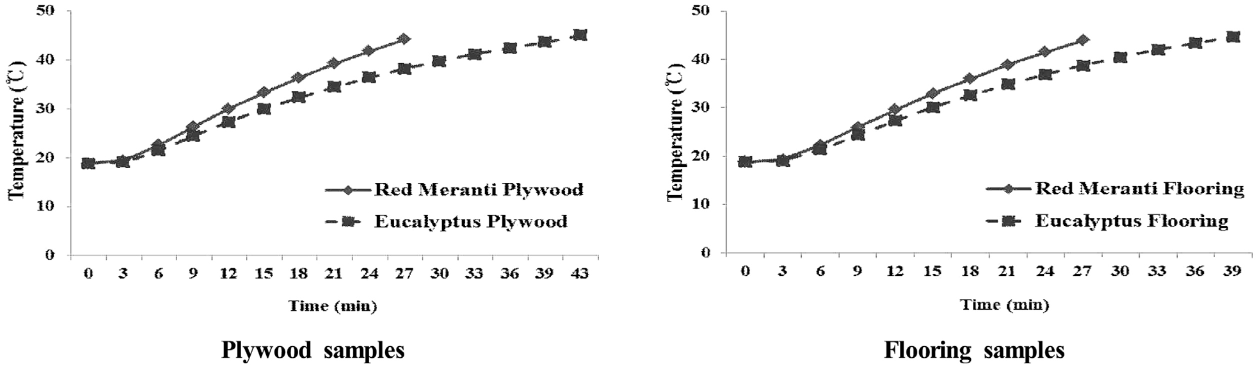
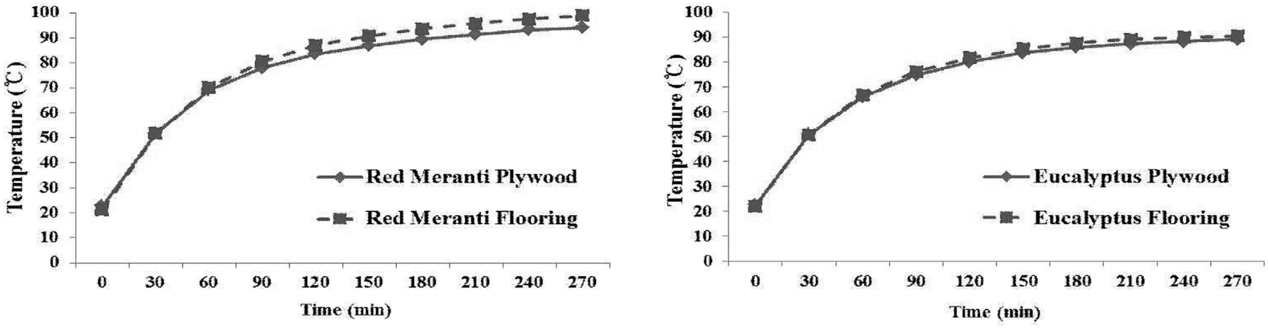


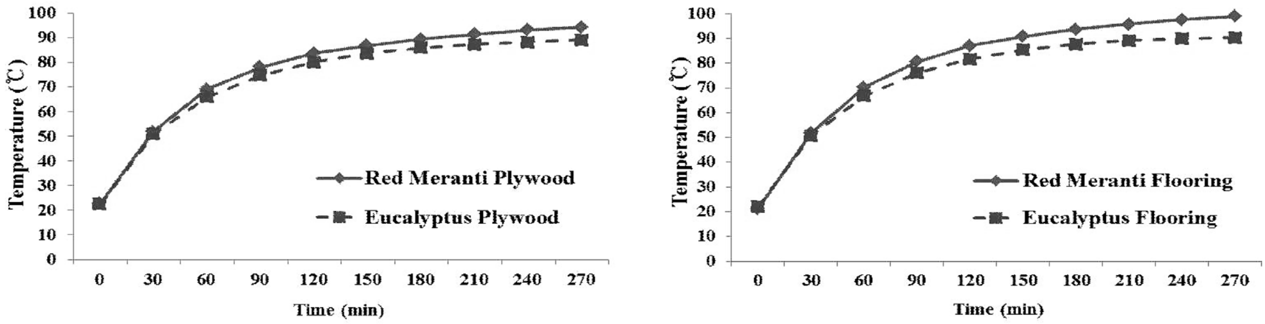

**Fig. 8.** Arrival Time of target temperature.




Red Meranti samples

Eucalyptus samples

**Fig. 9.** Maximum temperature of different species.




Plywood samples

Flooring samples

**Fig. 10.** Maximum temperature of different manufacturing.

veneer.

2. The flooring process improved the warping under different conditions. The causes of the linear shrinkage and expansion were different and depended on the use environment. A larger density difference impacted the deformation on the heating panel.
3. The warping and deformation were improved by the stress from the HPM layer, with the exception of the height difference for the floor.
4. The samples that had a low density gradient had better conductivity. Moreover, they were much more energy efficient.

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