Warping and Surface Checking Analysis of Engineered Wood Flooring for Heating Systems

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The objective of this paper was to investigate the warping and surface checking of engineered wood flooring that was exposed to a heating system. The effects of decorative veneer type, wood structure, and wood shape on warping and surface checking were studied in a laboratory with a simulated heating system. Poplar/seven layer plywood engineered hardwood (structure C) or a 9 mm think poplar substrate layer wood was used, which contained the two veneer surface layers, structure A and structure B. For each structure, two shapes (mono-block or three splice) were tested, and a total of eight different veneer wood types were used. The highest degree of warping was seen in *Eucalyptus* or sapele veneer types. The degree of warping was the greatest for structure C with mono-block, followed by structure A with mono-block, structure C with three splice, and structure A with three splice. According to the surface checking tests for wood type, American ash, eucalyptus, maple, or birch exhibited the easiest wear, whereas, eastern black walnut exhibited the hardest wear. The surface checking tests revealed that the ranking from easiest to hardest wear was structure B, structure A, and structure C.

Keywords: Engineered wood flooring; Warping; Surface checking; Decorative veneer; Flooring structure

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INTRODUCTION

Engineered wood flooring consists of a thin decorative veneer bonded onto sawn wood or plywood, with poplar panels using adhesives such as urea-formaldehyde (UF) and melamine-formaldehyde (MF) resins under the conditions of a hot press (Kim and Kim 2006). Engineered wood is widely used in the flooring sector for heating systems because of its excellent properties, which include high stability, less distortion, and minimal quality flaws when exposed to a long-term high temperature environment (Lu *et al.* 2005). Therefore, the market share of engineered wood flooring increases each year, worldwide.

Unlike other construction materials, such as stone, cement, concrete, metal, engineering plastics, *etc*., wood is a biological material. Wood distinguishes itself from other materials because of its moisture content, which is an inherent characteristic. The quality of a wood product depends largely on the moisture content, the percentage of which may predispose it to warping, checking, and distortion (Bendz-Hellgren and Stenlid 1998; Inoue *et al.* 2008). Blanchet *et al*. (2005) found that the non-homogeneous adsorption or desorption of moisture by engineered wood flooring may induce its deformation, thus decreasing the product value. Therefore, these researchers developed a finite elemental model of the hygromechanical cupping in engineered wood flooring and used it to predict deformation (Blanchet *et al.* 2005). Blanchet (2008) also assessed engineered wood flooring components for aging performance, comparing different substrates, surface components, and cold set adhesives. It was found that substrates and surface components will impact long-term performance properties, such as aging resistance. Of the adhesives tested, epoxy exhibited poor gluing and delamination, whereas EPl adhesives exhibited the best performance in terms of aging (Blanchet 2008). Other research (Fang *et al.* 2012a,b) has explored the use of oil-heat treatment applied to densified wood to reduce the hygroscopicity and improve mechanical properties of wood veneers. This investigation leads to the development of a prototype of engineered wood flooring using sugar maple with hygrothermally densified surface layers. It was found that thin sugar maple lumber densified at 200 °C under combined effects of steam, heat, and pressure with a heat-resistant fabric was more suitable for engineered wood flooring. The purpose of this work was to investigate the properties of engineered wood flooring when exposed to a heating system for an extended period of time.

EXPERIMENTAL

Materials

Samples evaluated in this study were engineered wood flooring, which consisted of a three layer construction: a surface layer, a substrate layer, and a 2 mm thick poplar veneer, as the backing layer (Fig. 1). All of the samples were provided by Dare (Jiangsu) Parquet of Jiangsu, China. According to the different properties of the substrate layers (9 mm thick poplar or 2 mm thick poplar/seven layer plywood), the floorings samples for the 9 mm thick poplar panels had two types of surface layers tested (structures A and B), whereas the 2 mm thick poplar/seven layer plywood panels were labeled structure C (Blanchet *et al.* 2008; Barbuta *et al.* 2010).

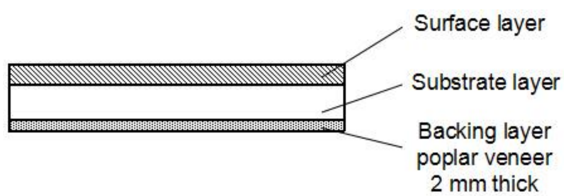


Fig. 1. Three layer construction of engineered wood flooring

The two types of surface layers used for the 9 mm thick poplar panels were: structure A, which contained a 4 mm thick decorative veneer surface layer and a 2 mm thick poplar veneer as backing layer (Fig. 2a) and structure B, which contained a 1.2 mm thick veneer surface layer and a 2.8 mm thick plywood backing (Fig. 2b).

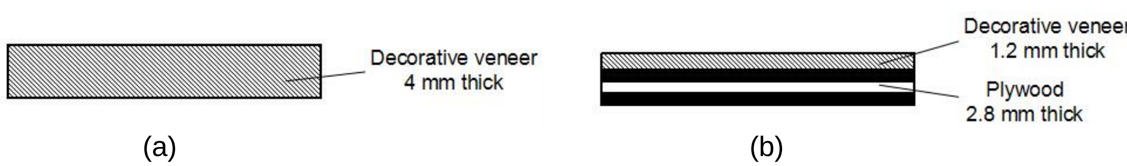
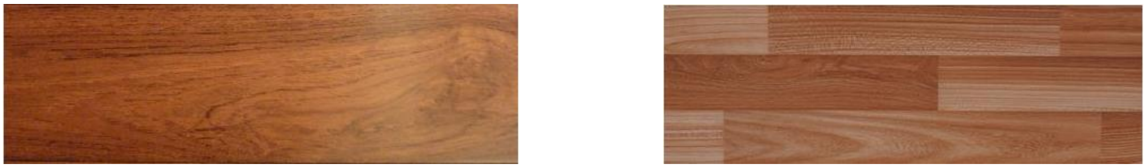


Fig. 2. The two structures of the surface layers when the substrate layer was 9 mm thick poplar panel

Structure C contained a seven layer plywood substrate layer (multi-ply engineered wood flooring), made with a 1.2 mm thick decorative veneer as the surface layer and a 2 mm thick poplar veneer as the backing layer.

The structures were further divided into shapes of the decorative veneer: mono-block (Fig. 3a) and three splice (Fig. 3b). All of the mono-block samples had the dimensions: 910 mm x 125 mm x 15 mm (length x width x thickness), and the three splice samples had the dimensions: 2200 mm x 205 mm x and 15 mm.



(a) (b)

Fig. 3. The two shapes of decorative veneers: (a) mono-block and (b) three splice.

Methods

Design of experiments

The factorial experimental design used to test for warping deformation is shown in Table 1.

Table 1. Factorial Experimental Design used in Testing Warping Deformation

Structure	Shape of decorative veneer	Species of decorative veneer
Structure A	Mono-block	Chinese oak
		Eucalyptus
		Maple
		Birch
		African ebony
		Eastern black walnut
		Pometia tomentosa
		Sapele
	Three splice	Chinese oak
		Eucalyptus
		Maple
		Birch
		African ebony
		Eastern black walnut
		Pometia tomentosa
		Sapele
Structure C	Mono-block	Chinese oak
		Eucalyptus
		Maple
		Birch
		African ebony
		Eastern black walnut
		Pometia tomentosa
		Sapele
	Three splice	Chinese oak
		Eucalyptus
		Maple
		Birch
		African ebony
		Eastern black walnut
		Pometia tomentosa
		Sapele

Table 2 shows the factorial experimental design when testing surface checking in this study; mono-block shaped samples were used for this test.

Table 2. Factorial Experimental Design used in Testing Surface Checking

Structure	Species of decorative veneer
Structure A	Eastern black walnut
	Eucalyptus
	Maple
	Birch
	American ash
Structure B	Eastern black walnut
	Eucalyptus
	Maple
	Birch
	American ash
Structure C	Eastern black walnut
	Eucalyptus
	Maple
	Birch
	American ash

Testing environment and equipment

As shown in Fig. 4, the heating system used in the experiment simulated the normal heating conditions and consisted of a laboratory room with the dimensions: 4 m x 3 m x 2.5 m, which was manufactured by O.S. Panto S.r.l (Italy). In research by Kim and Kim (2005), a similar environment containing a hot water pipe was used for interior warming by an attemperator, which was installed outside, buried in the cement ground. Above the ground layer, a coating of thin, plastic film was laid to provide a silencing barrier for when people tread upon the floor. Engineered wood flooring was laid on top of the plastic film. In addition, the laboratory was equipped with a humidifier, which regulated the overall humidity of the environment.

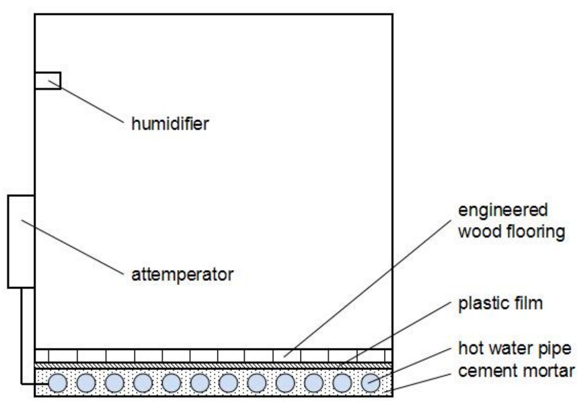


Fig. 4. The testing environment

As Kang *et al.* (2003) have explored, the ideal flooring surface temperature may range from 22.0 to 38.8 °C. Considering the degree of comfort of a human subject, the temperature of the testing environment was set at 25 ± 2 °C and the relative humidity was set at 40 ± 5%. To account for any heat loss from the heating system, the temperature in the attemperator was set at approximately 30 °C. And the primary equilibrium moisture content of samples was about 12%.

Warping and surface checking measurements

To calculate the warping measurement, as shown in Fig. 5, the samples were placed on an experiment table with the concave side facing up. Then, steel rulers were adjoined to the long sides of sample, and a Feeler gauge, model W2868B, produced by Wynn's located in Guangzhou, China, was used to measure the largest chord height. The warp degree in width was calculated by the ratio of chord height to actual width. In this study, the primary warp degree and moisture content of every samples was measured and recorded. In addition, the variation of the warp degree and moisture content was measured every seven days, and this process was repeated four times.

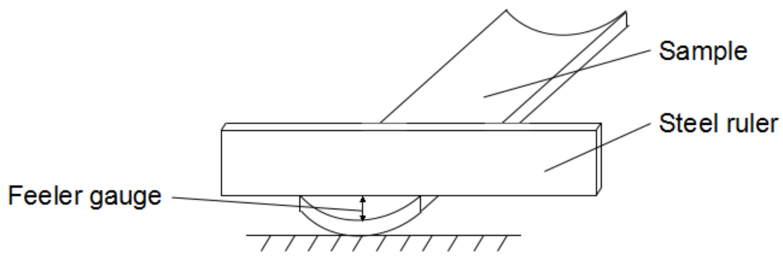


Fig. 5. The picture of warping measurement

The surface checking measurement was conducted by laying the samples on the ground to observe the surface condition. This was repeated every seven days, and the appearance of the wood was recorded each time by visual inspection and ruler measurement (*i.e.*, the total length of the checks and number of checks per board).

RESULTS AND DISCUSSION

Warping Deformation of Engineered Wood Flooring

Table 3 shows the average variation that is the D-value between the warping measurements before and after the test in the heating system.

Table 3. Variation in Warping Deformation of Engineered Wood Flooring

Structure	Shape of decorative veneer	Chinese oak	Eucalyptus	Maple	Birch
A	Mono-block	0.148%	0.087%	0.156%	0.124%
	Three splice	0.336%	0.233%	0.366%	0.243%
C	Mono-block	0.116%	0.042%	0.122%	0.092%
	Three splice	0.188%	0.105%	0.197%	0.142%
Structure	Shape of decorative veneer	African ebony	Eastern black walnut	*Pometia tomentosa*	Sapele
A	Mono-block	0.119%	0.132%	0.154%	0.081%
	Three splice	0.289%	0.266%	0.309%	0.234%
C	Mono-block	0.079%	0.084%	0.111%	0.036%
	Three splice	0.138%	0.146%	0.198%	0.108%

The evaluation was over the duration of one month for three repeat measurements on the same board. The experimental design enabled there to be 32 possible comparisons (2 structures × 2 shapes × 8 species), as shown in Table 3.

Table 4 shows the analysis of variance (ANOVA) results applied to the variation in warping deformation.

Table 4. Summary of ANOVA Applied to the Variation in Warping Deformation (Table 3)

Effect	Degree of freedom	F-value	Pr>F
Type of structure	1	3950.308	<0.0001
Type of shape	1	7047.293	<0.0001
Structure × shape	1	343.237	<0.0001
Species of decorative veneers	7	1149.686	<0.0001
Structure × species	7	7.249	<0.0001
Shape × species	7	23.081	<0.0001
Structure × shape × species	7	11.433	<0.0001

As shown in Tables 3 and Table 4, the warp degree for each of the samples indicated an obvious percent change in structure over the duration of the heating trial. Three influencing factors considered in the discussion were the structure, the shape of decorative veneer, and the species of wood veneer. Figure 5 shows the effects of different wood pairings on warping deformation.

Figure 6, compares the different structures (structure A and structure C), when the shape of decorative veneer was mono-block (the blue and the red line in the figure). Although the warp degrees of eight species differed from one another, the warp degree of structure A was higher than structure C. In other words, structure A was more prone to warping than structure C. Likewise, when the shape of decorative veneer was three splice (the green and the black line in the figure), the warp degree of structure A was also higher than structure C.

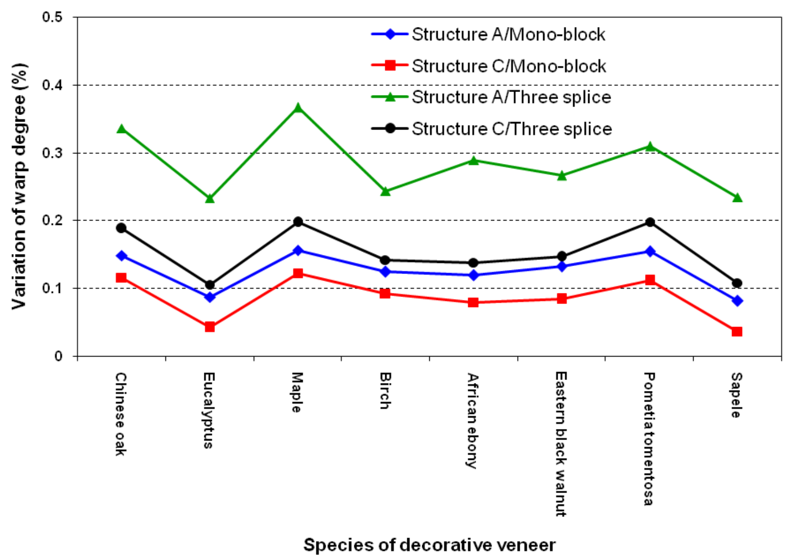


Fig. 6. The effect of surface wood species and type of core layer on warping deformation for engineered wood floorings

By comparing different shapes of the decorative veneer (mono-block and three splice), it appeared that the shape of three splice was more prone to warping than the mono-block shape, which was independent of structure or species of wood. When the different species of decorative veneer were compared, it was found that the Chinese oak, maple, and *Pometia tomentosa* species showed the greatest degree of warping, while the eucalyptus and sapele species showed considerably smaller changes in structure (Fig. 6).

The variation for the degree of warping was connected with the percent moisture content of the wood (Milota 2000; Cai 2008). Figure 6 shows the variation in the trend of warping and the percent moisture content.

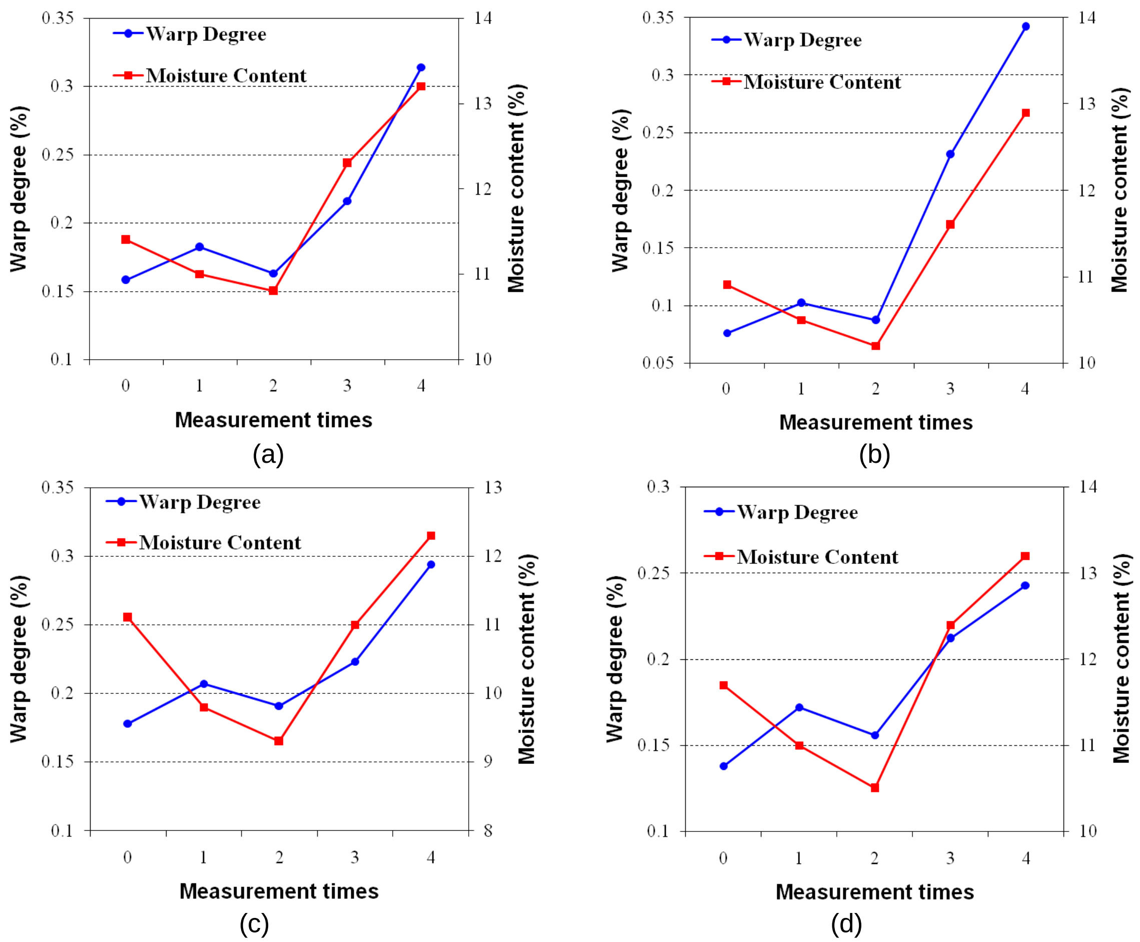


Fig. 7. The variation trend for the degree of warping and the moisture content (%): (a) structure A with mono-block and maple, (b) structure A with three splice and eastern black walnut, (c) structure C with mono-block and Chinese oak, and (d) structure C with three splice and eucalyptus

In Fig. 7, the moisture content of randomly selected samples showed little change when the relative humidity of the testing environment was approximately 40%. However, the wood from the raw material of the samples possessed the performance characteristic of hygroscopicity. As a consequence, the moisture content of samples changed. However, the degree of this change was not obvious. In Fig. 7, the moisture content of engineered wood flooring tended to increase, and then slightly decrease, while the degree of warping tended to increase, then decrease, and increase again. This indicated that the variation in the degree of warp was concurrent with the moisture content late into the experiment. In other words, the higher the moisture content of engineered wood flooring, the worse the degree of warping. However, the first three measurements of moisture content and warp degree did not fully conform to the results of the late experiment. The possible reason was that the higher the temperature of the environment, the greater the tendency towards warping at the onset of the experiment. Meanwhile, the higher temperature environment additionally caused evaporation of water and a reduction of the moisture content in the wood, which was a gradual process.

Surface Checking of Engineered Wood Flooring for the Heating System

The evaluation index of surface checking of engineered wood flooring in this paper was the time when the surface checks first appeared, the total length of checking, and the number of checks per board. When the engineered wood flooring had been tested in the heating system every seven days for a total four observations, the results of surface checking observed are shown in Table 5.

Table 5. Results of Surface Checking

Measurement times	Structure	The species of decorative veneer				
		Eastern black walnut	Eucalyptus	Maple	Birch	American ash
1	A	√	√	√	√	√
	B	√	√	√	√	×
	C	√	√	√	√	√
2	A	√	√	√	√	×
	B	√	×	√	×	×
	C	√	√	√	√	√
3	A	√	×	√	×	×
	B	√	×	√	×	×
	C	√	√	√	√	×
4	A	√	×	×	×	×
	B	√	×	×	×	×
	C	√	√	√	√	×

√: represents no surface checking; ×: represents surface checking

As can be seen in Table 5, the factors that influenced the surface checking of engineered wood flooring were the structure and the species of veneer. Of the five decorative veneers evaluated, eastern black walnut was the last to develop surface checking, while American ash developed surface checking the quickest. When comparing the observations from the three different structures, the results indicated that surface checking developed in structure B the earliest, while structure C resisted surface checking.

The second evaluation index of surface checking was the total length of checking for the different samples (Fig. 8). Among all the species of veneer, eucalyptus, maple, birch, and American ash contained the most surface checks. Regardless of the structure, the total length of the checks for the engineered wood flooring with the American ash veneer was the largest, while the birch veneer was the smallest. An analysis of the total length of checking dependent upon the structure of the wood with the same veneers yielded the following order in decreasing amounts: structure B > structure A > structure C. Thus, structure B was most likely to generate checking, while structure C was the least likely.

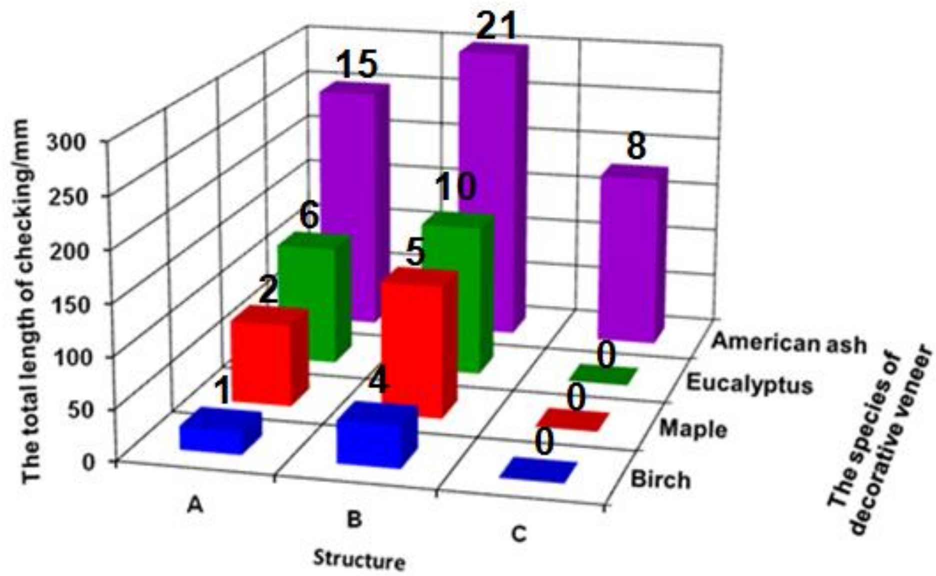


Fig. 8. The total length and number of checking for different structures and species of decorative veneer

Figure 8 also shows the number of checks (on the bar) as the third evaluation index. The number of checks was ranked from smallest to largest, as follows: birch, maple, eucalyptus, and American ash. The result indicated that the engineered wood flooring with American ash veneer was more prone to checking, with eucalyptus as second, and birch as the most resistant. According to structure, the amount of checking was smallest for structure C and was largest for structure B. Therefore, structure B was easier to crack than structures A and C.

Among all of the samples tested, surface checking was considered the most important when choosing a suitable engineered wood flooring for use in a heating system. Therefore, structure C for the engineered wood flooring with birch veneer was the optimum choice for use in a heating system.

CONCLUSIONS

1. A comparison of the engineered wood flooring with different veneers, independent of structure, it turned out that the eucalyptus and sapele species was difficult to yield warping deformation, followed by birch, African ebony, and eastern black walnut. Chinese oak, maple and *Pometia tomentosa* was easy to yield warping deformation.
2. The flooring structure of samples with the same veneer influenced the variation in warping. Multilayer engineered wood flooring (structure C) with mono-block veneer was difficult to yield warping deformation, followed by three-layer engineered wood flooring with the surface layer made with thick veneer (structure A) with mono-block veneer and structure C with three splice decorative veneer. Structure A with three splice decorative veneer was easy to yield warping deformation.

3. The engineered wood flooring with eastern black walnut veneer was the least likely to develop surface checking. However, American ash was the most likely to develop surface checking.
4. By analyzing the influence of flooring structure on surface checking, it was found that structure C appeared to maintain the best surface condition, followed by structure A. The three-layer engineered wood flooring with the surface layer made with plywood (structure B) appeared to have the worst surface condition and the most severe surface checking of all the samples.
5. In conclusion, structure C of engineered wood flooring was judged to be the best for the construction tested in this study in consideration of warping and surface checking.

ACKNOWLEDGMENTS

The authors are grateful for the support from the National Science and Technology Support Plan of China (No. 2012BAD24B01) and the Priority Academic Program Development of the Jiangsu Higher Education Institutions (PAPD).

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Article submitted: March 11, 2015; Peer review completed: May 15, 2015; Revisions accepted: May 24, 2015; Published: June 8, 2015.
DOI: 10.15376/biores.10.3.4641-4651