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HONEYCOMBING AND DEFORMATION OF SIX WOOD SPECIES AND THEIR RELATIONSHIP WITH SEVERAL PHYSICAL PROPERTIES

(Pecah Dalam dan Deformasi pada Enam Jenis Kayu serta Hubungannya dengan Beberapa Sifat Fisik)

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ABSTRACT

It is presumed that the wood susceptibility to drying defects is related to several physical properties. This paper examines the drying defects: honeycombing and deformation of six wood species (trema, fast growing teak, bayur, jabon, angsana and lamtoro) during high temperature drying and analyses their relationship with initial moisture content, T/R shrinkage ratio and density. Terazawa method was used to examine the defect during high temperature drying. Result shows that after high temperature drying, lamtoro suffers the worst honeycombing (level 4-6), and fast growing teak deforms severely (level 4-6). Regression analysis shows multiple regression models using all physical properties as predictors provides better estimation on deformation and honeycombing than single-predictor regression models. The multiple regression model for each defect could explain 57.52% and 39.46% of variation in deformation and honeycombing, respectively.

Keywords: Honeycombing, deformation, high temperature drying, defect, predictor

ABSTRAK

Diasumsikan bahwa perbedaan kecenderungan setiap jenis kayu terhadap cacat pengeringan dipengaruhi oleh beberapa sifat fisik kayu. Tulisan ini mempelajari terbentuknya pecah dalam dan deformasi pada beberapa jenis kayu (trema, jati cepat tumbuh, bayur, jabon, angsana, dan lamtoro) serta menganalisa hubungannya dengan kadar air awal, rasio penyusutan T/R, dan kerapatan. Metode Terazawa digunakan untuk meneliti cacat pengeringan selama pengeringan suhu tinggi. Hasil studi menunjukkan bahwa kayu trema dan lamtoro mengalami tingkat pecah dalam paling buruk (4-5/6). Kayu trema dan jati cepat tumbuh mengalami tingkat deformasi paling buruk (4-5/6). Analisis regresi lebih lanjut menunjukkan bahwa model regresi berganda yang menggunakan kadar air awal, rasio T/R dan kerapatan sebagai penduga memberikan dugaan tingkat nilai deformasi dan pecah dalam yang lebih baik dibandingkan model regresi dengan penduga tunggal. Setiap model regresi berganda yang dibuat dapat menjelaskan sekitar 57,52% dan 39,46% variasi data deformasi dan pecah dalam yang terbentuk.

Kata kunci: Pecah dalam, deformasi, pengeringan suhu tinggi, cacat, pendugaan

I. INTRODUCTION

Currently, the use of young wood for furniture or other construction purposes is becoming more popular. Whilst teak (*Tectona grandis* L.f.) and mahogany (*Swietenia mahagoni* (L.) DC.) are still the favourable species for, particularly, producing wooden furniture, other alternative wood species have also been used for this purpose (Ozarska, 2011). These other alternative woods, particularly in West Java, include bayur (*Pterospermum javanicum* Jungh.), angsana (*Pterocarpus indicus* Willd.), lamtoro (*Leucaena leucocephala* (Lam.) de Wit), jabon (*Anthocephalus chinensis* Hassk.), trema (*Trema orientalis* (L.) Blume) and many more. The use of young teak generated from fast-growing provenance has also attracted some industries.

In the production of high-value added products, such as furniture, from wood, drying process is a crucial stage. A specific drying schedule is often applied in order to reduce the drying time, energy consumption and improve the use of dried wood (Shahverdi, Dashti, & Hossein, 2011).

Nevertheless, not every wood species is easy to dry. The difficulty in drying process is commonly met when the wood used is from the plantation forest. The logs from the plantation forest are not only still young but also having features which could affect its drying process. The features include high growth stresses (Ozarska, 2011) and high variation of moisture content in the wood (Basri & Wahyudi, 2013; Glass & Zellinka, 2010).

Several defects could easily occur in young wood during its drying process. Drying defects are flaws that develop in a wood product during the drying process and decreases its value (Simpson, 1991). These defects include end check, surface check, honeycombing (internal check), collapse and deformation (bow, spring, cup or twist) (Yuniarti, 2015).

Of all those defects, honeycomb and deformation are considered to be the two most important for the industries. Whilst end check and surface checks will normally close as the moisture continues decreasing, internal check behaves differently once it develops. In addition, its presence in the affected board is invisible and can only be seen if the boards are resawn. The presence of any types of deformation also affects the board quality. Due to the occurrence of deformation, the boards will probably need to be resawn/cut to obtain the straight, free-defect boards that meet the industry requirement.

Different wood species will develop different level of susceptibility to honeycomb and deformation during their drying process. This character is assumed to be influenced by several wood physical properties such as density, initial moisture content of wood and others. Nevertheless, the significant relationship between the physical wood properties and the wood susceptibility to honeycomb/deformation has not been examined yet. As well, it still remains unknown whether the physical wood properties can or cannot be used to predict the development of these defects during the drying process of a particular wood.

Information on the relationship between the honeycomb and deformation with several physical properties is crucial. It can be utilized to provide early estimation of possible development of honeycomb or deformation during the drying process of a particular wood. Realizing there is a gap of knowledge in this particular area, this study is then developed for two purposes. The first one is to examine the development of honeycomb and deformation in several wood species. The second is to assess the relationship of the developed honeycomb and deformation with several wood physical properties (such as density, initial moisture content and tangential-radial shrinkage ratio).

II. MATERIAL AND METHOD

A. Material and Equipments

Six wood species were used as main materials for this study, which were bayur (*P. javanicum*), angsana (*P. indicus*), lamtoro (*L. leucocephala*), jabon (*A. chinensis*), trema (*T. orientalis*) and fast-growing teak-JUN (*T. grandis*). Approximately 2-3 trees were collected for for each wood species. Except the fast-growing teak, other woods were collected from community-based plantation forest in West Java.

The equipments used included bandsaw, balance, laboratory oven, digital caliper and universal testing machine (UTM). The tests for physical properties and drying defects were carried out at wood physical-mechanical properties and drying laboratories of the Center of Forest Products Research and Development, Bogor.

B. Research Procedure

1. Drying defect test

The test and scoring for drying defect followed the Terazawa method. Approximately 10 tangentially-sawn boards, measuring 100 mm (width) x 2000 mm (length) x 20 mm (radial/thickness) were collected randomly for each wood species. These tangentially-sawn boards were further re-sawn to produce defect-free samples with the dimension of each sample was 100 mm (tangential/width) x 200 mm (longitudinal/length) x 20 mm (radial/thickness). Two biscuits at a length of 20 mm, clamping the drying defect samples, were also collected and used to obtain the initial moisture content of each sample.

The samples were dried in an oven at 100°C until an average moisture content of 1% was reached. During the drying test, each sample was observed for the presence of deformation and honeycombing. Score from 1 to 7 was given for deformation found in the wood whilst score from 1 to 6 was labelled for the presence of honeycomb defect. In every scoring, the higher the score means a greater defect (Basri, 2011).

2. Physical properties test

The physical properties being tested were density and tangential-radial shrinkage ratio. Ten replications were used for each wood species and physical property. The test and the sample collection were performed according to ASTM Standard D143(ASTM, 2011).

C. Data Analysis

Data on drying defects was tabulated with Excel and analyzed. Further regression analysis was performed to assess the relationship between the physical properties (density, tangential-radial shrinkage ratio, initial moisture content) and the level of deformation and honeycomb in wood. Replication from each species was combined to produce 60 samples in total. For regression analysis purpose, the procedure used is "all possible regression" considering that the number of predictor/independent variables is only three (Draper & Smith, 1966). The procedure resulted in different simple and multiple regressions that were further compared. A model can be used to estimate the presence of defects if its P-value is significant or very significant (less than 0.5). SAS software was used to perform the statistic analysis.

III. RESULTS AND DISCUSSION

A. Physical Properties, Deformation and Honeycombing

Table 1 shows the average values of the physical properties and the scoring level of the defects occurred in the six wood species. All wood species investigated have T/R shrinkage values higher than two, indicating their poor dimensional stability. The density values of all wood species ranged from 300 kg/m^3 to 870 kg/m^3. Trema had the lowest average density value (380 kg/m^3), whilst lamtoro had the highest average density (800 kg/m^3). The initial moisture content of all species prior to drying process investigated was still above fiber saturation point, ranged from 44.23% to 107%.

Table 1 further shows two of the six species studied, trema and lamtoro, tend to develop severe honeycomb during their drying process. Lamtoro has the highest scoring level of honeycomb (4-6), whilst trema's scoring level of honeycomb is 4-5. Both angsana and fast-growing teak JUN also develop some honeycomb, but at lighter level (1-3) than trema or lamtoro (Figure 1). Jabon and bayur are found less susceptible to honeycomb with a defect level of only 1.

Honeycombing (internal check) in lumber is the separation of the fibers in the interior of the piece, usually along the rays. The failures can be the extended result from surface and/or end checks. According to Johansson (2005) *in* Yang and Normand (2012), the presence of honeycomb defect is affected by the initial moisture content of the board, the wood mass loss, the presence of pith and the speed of drying process.

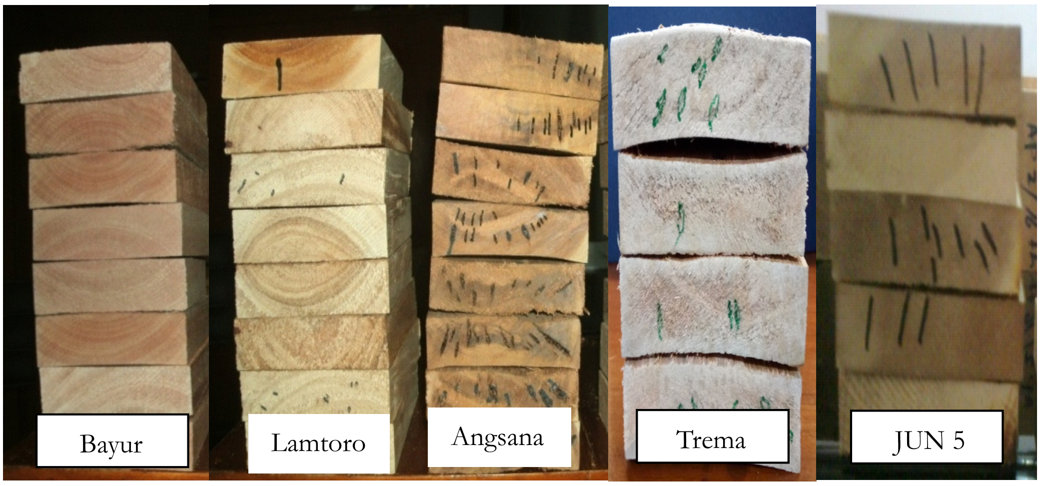

Figure 1. The honeycomb was found merely in angsana, lamtoro and fast-growing JUN teak and not in trema, bayur and jabon (picture was not taken)[1]
Gambar 1. Pecah dalam ditemukan pada kayu angsana, lamtoro, dan jati JUN cepat tumbuh; dan tidak dijumpai pada kayu trema, bayur, dan jabon (Foto untuk jabon tidak diambil)

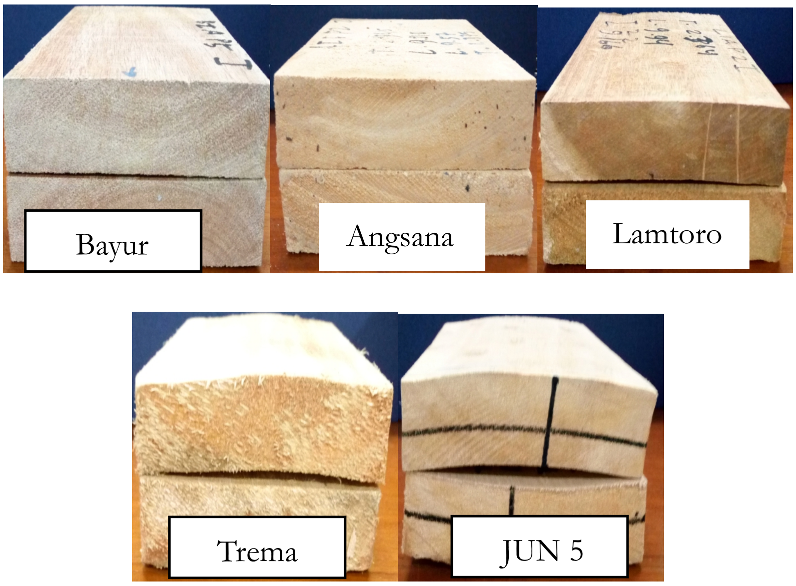

Figure 2. Deformation was found in all species but with different degree (Jabon picture was not taken)[2]
Gambar 2. Deformasi ditemukan pada semua jenis kayu dengan level yang berbeda (Foto Jabon tidak diambil)

All six species investigated is found susceptible to deformation/warping (Figure 2). Fast-growing teak (JUN) has the highest scoring level of deformation (4-6), whilst Trema is in the second rank with the scoring level of 4-5. Lamtoro, bayur and angsana share the same scoring level of deformation (2-4). On the other hand, jabon has the widest variability of the scoring level of the deformation occurred during its drying process, which is 1-5 (Table 1).

[1] The experiment was carried out separately for the wood species being examined. The picture of jabon was not taken during its experiment.
[2] Please refer to footnote number 1

Table 1. Average values and standard deviation of initial moisture content, density, T/R ratio and ranges of each wood's defect scoring level

Tabel 1. Nilai rata-rata dan standard deviasi kadar air awal, kerapatan, rasio T/R dan kisaran level skoring cacat untuk setiap jenis kayu

Species (*Jenis*)	Initial moisture content (*Kadar air awal, %*)	Density (*Kerapatan*, kg/m³)	T/R (*Tangensial/Radial*)	Defects score[1] (*Skor cacat*)	
				Deformation[2] (*deformasi*)	Honeycomb[2] (*pecah dalam*)
Trema	68.86 – 85.53 ***(79.46 ± 5.02)***	300 – 420 ***(380 ± 44.02)***	2.80 – 5.10 ***(4.10 ± 0.87)***	4 – 5	4 – 5
Lamtoro	70.1 – 98.51 ***(84.04 ± 9.48)***	740 – 870 ***(800 ± 47.48)***	2.30 – 3.60 ***(2.90 ± 0.38)***	2 – 4	4 – 6
Jabon	43.00 – 107.00 ***(76.72 ± 18.17)***	350 – 470 ***(390 ± 45.90)***	2.80 – 5.60 ***(3.20 ± 1.41)***	1 – 5	1
Bayur	44.23 – 65.55 ***(52.01 ± 7.51)***	460 – 600 ***(530 ± 43.97)***	2.20 – 2.50 ***(2.30 ± 0.10)***	2 – 4	1
Angsana	50.11 – 74.34 ***(64.52 ± 7.84)***	600 – 700 ***(640 ± 33.73)***	2.20 – 2.50 ***(2.40 ± 0.12)***	2 – 4	1 – 3
Teak (JUN)	61.07 – 99.29 ***(83.29 ± 12.12)***	520 – 600 ***(560 ± 27.59)***	2.30 – 4.70 ***(3.30 ± 0.66)***	4 – 6	1 – 3

Remarks: [1)] Source: Basri (2011); [2)] 1 = very light; 2 = light; 3 = rather light; 4 = fair; 5 = rather poor; 6 = poor; 7 = very poor. Figures printed in bold and italic show average values and standard deviation

Keterangan : [1)] *Sumber: Basri (2011);* [2)] *1 = sangat ringan; 2 = ringan; 3 = cukup ringan; 4 = sedang; 5 = agak buruk; 6 = buruk; 7 = sangat buruk. Angka diketik dengan huruf tebal dan miring menunjukkan nilai rata-rata dan standard deviasi*

It is assumed that the tendency to warping/ deformation is due to the high content of initial moisture. In general, higher moisture content causes wood sample to warp – (Basri, Yuniarti, Wahyudi, Saefudin, & Damayanti, 2015; Ofori & Brentuo, 2005). Naturally, free water in the wet wood will be the first moisture component to evaporate from the wood cell lumen during a drying process. The free water movement shrinks the cell wall lumen and causes uneven shrinkage between wood surfaces and inside the wood. As a further results, the wood warps (Glass & Zellinka, 2010). In mature timber, wood shrinks below the fiber saturation point. However in young plantation timber, it is found that the shrinkage starts above fiber saturation point when the free water starts to evaporate from the timber (Simpson, 1991; Yuniarti, 2015).

B. Correlation Between Physical Properties and the Drying Defect

Table 2 shows the relationship between each physical property or their combination and the deformation in the wood during the drying process. Except for the simple regression model with density as the only predictor, other simple or multiple regression models show a positive correlation (r value is +) between the deformation level and the predictor(s). A positive correlation indicates that higher value of predictor or their combinations will result in higher level of deformation.

Based on the p-values, Table 2 shows that if simple regression model is to be used to estimate the deformation value in wood, initial moisture content or T/R shrinkage ratio is the physical property that can be used for the purpose. Higher initial moisture content or T/R shrinkage ratio of wood will potentially result in higher deformation level. Wood with a T/R shrinkage ratio around or higher than 2 is usually harder to dry and need milder kiln condition than the wood with a T/R shrinkage ratio below 2 (Basri, Saefudin, Rulliaty, & Yuniarti, 2009). Nevertheless, Basri (2011) has also warned that wood with very high tangential shrinkage is still prone to high percentage of shrinkage eventhough its T/R shrinkage ratio is lower than 2.

Table 2. Simple and multiple regression models to estimate the relationship between each physical property or their combination and deformation in wood

Tabel 2. Model regresi sederhana dan berganda untuk menduga hubungan antara setiap sifat fisik atau kombinasinya dengan deformasi pada kayu

No.	Regression models (*Persamaan regresi*)[1)]	R	R^2	P
1.	Y1 = -0.3277 + 0.0565 X1	+0.6605	0.4362	0.0001**
2.	Y1 = 0.4488 – 1.1446 X2	-0.1296	0.0168	0.3231^{NS}
3.	Y1 = 0.8115 + 0.9902 X3	+0.6975	0.4865	0.0001**
4.	Y1= 0.3692 + 0.0569 X1 – 1.3090 X2	+0.6770	0.4582	0.0001**
5.	Y1= -0.5578 + 0.0321 X1 + 0.6664 X3	+0.7583	0.5750	0.0001**
6.	Y1= 0.1253 + 0.9643 X2 + 1.0408 X3	+0.7051	0.4972	0.0001**
7.	Y1= -0.6360+0.0316X1+0.1391X2 + 0.6786X3	+0.7584	0.5752	0.0001**

Remarks : [1)] Number of sample = 60; Y1 = Deformation/warping; X1 = initial moisture content (%); X2 = density; X3 = T/R ratio; NS = not significant (p > 0.05); ** = very significant at α = 1% (p < 0.01); * = significant at α = 5% (0.05 < p < 0.01); r = correlation coefficient; R^2 = determination coefficient; P = probability value

*Keterangan :[1)] Jumlah contoh uji = 60; Y1 = Deformasi/perubahan bentuk; X1 = kadar air awal (%); X2 = kerapatan; X3 = rasio T/R; NS = Tidak nyata (p > 0,05); ** = sangat nyata pada a = 1% (p < 0,01); * = nyata pada a = 5% (0,05 < p < 0,01); r = koefisien korelasi;* R^2 *= koefisien determinasi; P = nilai peluang*

On the other hand, all multiple regression models, which were developed with the combination of two or all physical properties applied (among initial moisture content, density and T/R shrinkage ratio), can be used to estimate the deformation level. Table 2 further shows that a multiple regression model, which uses the initial moisture content, density and T/R shrinkage ratio of wood as its independent variables, provides better estimation of deformation level in the wood than other regression models. The R^2 value of this particular multiple regression model is 0.5752, meaning that approximately 57.52% of the variability in the values of deformation in wood can be explained with initial moisture content, density and T/R ratio. In addition, the model also shows that a combined increase of initial moisture content, density and T/R shrinkage values of the wood will potentially increase the deformation level occurs in the wood.

The next best multiple regression model can be determined according to the "all possible regression" procedure explained in Draper and Smith (1966). The procedure stresses the importance of any predictor variables that give the highest R^2 value (or the second highest) in a simple regression model to be included in any multiple regression models. Therefore, a multiple regression model with T/R ratio and initial moisture content as its predictor variables, shown as equation 5 in Table 2, can become the next option to estimate the deformation level.

Table 3 shows the relationship between each physical property or their combination with the honeycomb level in the wood during the drying process. Based on their p-values, all simple and multiple regression models listed in Table 3 can be used to estimate the value of honeycomb defect in the wood.

Similar to the result obtained for deformation, the multiple regression model with three predictors (initial moisture content, density and T/R shrinkage ratio of wood) provide better estimation of honeycomb level in the wood than any simple regression models. Approximately 39.46% of the variability found in the value of honeycomb defect in the wood can be explained with initial moisture content, density and T/R shrinkage ratio. A combined increase in the values of initial moisture content, density and T/R shrinkage ratio of wood will potentially increase the honeycomb level occurs in the wood. However, since the R^2 value of this multiple regression model is still relatively low (only 0.3946), other parameters might be required to be added to improve the model's power.

Table 3. Simple and multiple regression models to estimate the relationship between each physical property or their combination and internal checks in wood
Tabel 3. Model regresi sederhana dan berganda untuk menduga hubungan antara setiap sifat fisik kayu atau kombinasinya dengan pecah dalam pada kayu

No.	Regression models (*Persamaan regresi*)[1)]	R	R^2	P
1.	Y2 = -0.9444 + 0.0497 X1	+0.4310	0.1858	0.0006**
2.	Y2 = 0.4887 + 4.0036 X2	-0.3369	0.1135	0.0085**
3.	Y2 = 0.4903 + 0.7281 X3	+0.3390	0.1149	0.0027**
4.	Y2 = -3.0010 + 0.0486 X1 + 1.8630 X2	+0.5398	0.2914	0.0001**
5.	Y2 = -1.0685 + 0.0365 X1 + 0.3594 X3	+0.4561	0.2080	0.0013**
6.	Y2 = -3.8723 + 6.1307 X2 + 1.0498 X3	+0.6186	0.3827	0.0001**
7.	Y2 = -4.2735 + 0.0166 X1 + 5.6960 X2 + 0.8590 X3	+0.6282	0.3946	0.0001**

Remarks : [1)] Number of sample = 60; Y2 = Internal checks; X1 = initial moisture content (%); X2 = density; X3 = T/R ratio; NS = not significant ($p > 0.05$); ** = very significant at $\alpha = 1\%$ ($p < 0.01$); * = significant at $\alpha = 5\%$ ($0.05 < p < 0.01$); r = correlation coefficient; R^2 = determination coefficient; P = probability value

Keterangan: [1)] *Jumlah contoh uji = 60; Y2 = Pecah dalam; X1 = Kadar air awal (%); X2 = Kerapatan; X3 = Rasio T/R ; NS = Tidak nyata (p > 0,05); ** = sangat nyata pada a = 1% (p < 0,01); * = nyata pada a = 5% (0,05 < p < 0,01); r = koefisien korelasi;* R^2 *= koefisien determinasi; P = nilai peluang*

Based on the “all possible regression” procedure in selecting the best regression equation (Draper & Smith, 1966), the two-predictor multiple regression model with initial moisture content as one of the predictors would be the next option. This is because, among other variables, this variable has given the best single predictor equation to estime the honeycombing level.

Both Table 2 and 3 show the density of wood is not reliable enough to be used alone as a single predictor in estimating both deformation and honeycomb level in the wood. The corresponding simple regression models for deformation and honeycomb defect with density as the predictor have the lowest R^2 values (0.0168 and 0.1135, respectively). This is possibly due to inconsistency in density pattern across the radial and axial direction of the wood (Cave & Walker, 1994 as cited in Basri, 2011).

Nevertheless, the result obtained from this study shows that density acts better as the predictor for drying defect when it is combined with initial moisture content or T/R ratio or both parameters in any multiple regression models. Replacing the density with specific gravity value will possibly provide better estimation of the drying defect. A study carried out by Simpson and Verrill (1997) has hown that the specific gravity of wood can be used to provide first estimation of a suitable drying condition for wood. Specific gravity has also been used to determine the strength class of wood (Martawijaya, Kartasujana, Kadir, & Prawira, 2005). Further investigation will be required to prove the proposition of the power of specific gravity in estimating the drying defect.

IV. CONCLUSION AND RECOMMENDATION

The study shows that the most severe internal checks/honeycombing was found in trema and lamtoro (scoring level of 4-6). On the other hand, the most severe deformation was found in fast growing teak (JUN) (scoring level of 4-6).

The study also shows that initial moisture content or T/R ratio are good single predictors to estimate the level of deformation and honeycombing level in the wood. Density, on the other hand, is less reliable.

Based on the R^2 values, the multiple regression models combining two or all physical properties as the predictor are better than the simple model in estimating the honeycombing or deformation level. The multiple regression models with three predictors can explain approximately 57.52% and 39.46% variation in the deformation and honeycombing, respectively. Considering the R^2 values of the 3-predictor multiple regression models are still considerably low, it is recommended to investigate and include other parameters to improve the model power.

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