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OPTIMIZATION OF L-SHAPED CORNER DOWEL JOINT IN PINE USING FINITE ELEMENT ANALYSIS WITH TAGUCHI METHOD

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ABSTRACT

The strength of the furniture corner-joints in pine remains unknown, and the lack of information restricts its use in furniture industry. Therefore, the aim of this study is to optimize the strength of L-shaped corner dowel joint in pine under compression loads using finite element analysis (FEA) with Taguchi method. By adopting a L_9-3^4 Taguchi orthodoxy array (OA), four experiment factors (i.e., structure style, tenon length, tenon diameter, and tenon gap), each at three levels, were carried out to determine the optimal combination of factors and levels for the von mises stress using ANSYS software. The results of Signal-to-Noise ratio (S/N) analysis and the analysis of variance (ANOVA) revealed that the optimal L-shaped corner dowel joint in pine is 45° Bevel Butt in structure style, 24 in tenon length, 6 in tenon diameter and 20 mm in tenon gap.

KEYWORDS: Finite element analysis, funiture joint, taguchi method, robust design.

INTRODUCTION

For decades, the destruction of forest resources with the population growth rate, the precious wood resources with high quality is scarce. Pine is an important fast-growing wood, which has been widely used as a potential environmental and sustainable raw material for the furniture and floor, on the basis of its acceptable strength and working properties (viz., light weight, fast growth, strong adaptability, easily processing, and beautiful natural texture). Nevertheless, compared to the other traditional solid wood species used in furniture, the weakness of pine in strength, stiffness, physical, mechanical properties, and surface appearance have limited its broader application in the furniture production .

In order to solve the various defects of pine and to increase its application scope, pine wood is commonly modified by chemical, physical, and biological methods to improve its properties including improvements in dimensional stability against moisture and bio-deterioration, mechanical property, and weathering resistance (Hill and Callum 2011). The properties mentioned above are sufficient to evaluate the performance quality of furniture structure. In furniture construction technology, the weakest points against heavy weights are indicated as the corner-joints of the furniture. (Yerlikaya 2012). Therefore, to strengthen furniture corner joint in pine have a great deal of importance. The L-shaped corner-joint is one of the most important furniture structure type manufactured and used nowadays for connecting leg, transom, and handrail. There is an important joint style usually used in a L-shaped corner-joint which is called butt joint with dowels. A dowel is a solid cylindrical rod usually made of wood. The dowel joint is employed in numerous, diverse applications in furniture structure including structural reinforcements in cabinet making and for furniture shelf supports. The dowel joint is divided into two parts: A hole which is bored in both objects and a dowel pin which is inserted into the aligned holes. At present, there are no reporting applications of L-shaped dowel furniture corner joint for pine.

Several studies of L-shaped furniture corner-joint made of hard wood or wood-based panel have been carried out by means of experiments and numerical simulation such as ANSYS finite element analysis. The L-shaped corner joints were examined for their diagonal tension and compression (Tankut and Tankut 2009; 2010). It was reported that the diagonal tensile strength of L-shaped corner-joint is greater than their diagonal compressive strength. Atar et al. (2009) investigated the tensile and compressive performances of corner-joints constructed with solid wood biscuits for case furniture. Best performance was achieved with melamine-coated fiberboards and the use of Desmodur Vinil Trie Ketonol Acetate (DVTKA) adhesive. Studies made on Dowel-welded L-shaped (Segovia et al. 2010) joints showed that only in mortise and tenon L-shaped joints, there is a considerable difference between tension and compression test results on the same L-joint, with such joints yielding higher strength in compression than in tension. Tankut and Tankut (2005) found that rectangular end mortise and tenons are about 15 % stronger than both round end mortise and tenons, and rectangular end tenons fitting into round end mortise joints. Meanwhile, joint geometry has a significant effect on the strength of those particular joints. Oktaee et al. (2014) reported that the optimum results of simple and haunched mortise and tenon furniture joints under tension and compression loads were obtained with joints constructed with 10 thick tenons that were 37.5 wide by 30 mm long. Tenon length was found to have the greatest effect on joint capacity, whereas tenon width was found to have a much smaller effect. Dalvand et al. (2014) investigated the bending moment resistance under diagonal compression load of corner doweled joints with plywood members. Experimental results indicated that the bending moment resistance under diagonal compressive load was increased by increasing the dowel's depth of penetration. Joints made with dowels of beech had higher resistance than dowels of hornbeam.

Finite element method is widely used in biomechanics and bioengineering to determine the stresses and strains in complicated mechanical systems (Dar et al. 2002). Meanwhile, finite element analysis (FEA) was proven to be helpful by identifying areas that are prone to weakness and failure. Some researchers have demonstrated that finite element analysis is a good technique for analyzing funiture construction (Eckelman and Rabiej 1984; Cai and Wang 1993; Smardzewski 1998; Colakoglu and Apay 2012).

In reference to the reviewed literature, most studies on L-shaped furniture corner- joint by using Finite Element method have focused on the enhancement of strength and stiffness by making the components and parts as large as possible. Although the investigation of these optimal methods have improved configuration properties, it has led to an increase in the cost of materials and variance of structure performance characteristics. Therefore, it is of critical significance to efficiently control all the design factors during the manufacturing of furniture corner-joint by an appropriate optimization method such as Taguchi method.

Taguchi method was developed by Taguchi and Konishi (Taguchi and Konishi 1987) and has been widely used in engineering to optimize the performance characteristics within a combination of design parameters, and in the design of quality systems. It has been proven as a simple and effective solution for experimental design (Taguchi and Konishi 1987; Taguchi 1990; Ross 1996). In Taguchi method, a special design of an orthogonal array (OA) with a minimum set of test data was used which would also reduce the time and cost. Taguchi method usually utilizes loss function to measure the performance characteristic deviation from the target value. The loss function is further transformed into the Signal-to-Noise ratio (S/N) to determine the quality of characteristics which is insensitive to the noise factors. In the Signal-to-Noise ratio, the combination of the factor level with the higher S/N ratio indicates the better performance characteristic. The design project consistent with the highest S/N ratio always yields optimal quality characteristics with minimum variance. In the Taguchi method, S/N ratio can be categorized in to three types: The lower the better, the higher the better and the nominal the better (Gu et al. 2014; Wu and Wu 2000). The S/N ratio with the lower the better characteristic can be expressed as:

$$\mathrm{S/N} = -10\lg\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \tag{1}$$

The S/N ratio with the higher the better characteristic can be expressed as:

$$\mathrm{S/N} = -10\lg\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \tag{2}$$

The S/N ratio with the nominal the better characteristic can be expressed as:

$$\mathrm{S/N} = -10\lg\left(\frac{1}{ns}\sum_{i=1}^{n} y_i^2\right) \tag{3}$$

where: y_i - the i-th experiment at the test,
n - the total number of trials in the test,
s - the standard deviation of.

In this study , the goal of finite element analysis using ANSYS software is to optimize the level of design factors to obtain the lowest von mises stress in the weakest point of L-shaped corner dowel joint. The lower the von mises stress is, the safer the L-shaped corner-joint is. Therefore, the S/N ratio for von mises stress with the lower the better characteristic Eq. 3 was chosen to obtain optimal design parameter and factor of L-shaped corner dowel joint in pine. Furthermore, analysis of variance (ANOVA) was performed to identify the significant contribution of each design factors to the variability in performance of the product (Gijo and Scaria 2010). Through ANOVA, the most significant design factor effecting the structure strength will be optimized in the robust design. Finally, a confirmation test can be conducted to verify the optimal design factors obtained from the parameter design. If the S/N ratio obtained in the optimal set is similar to the predicted values with the experimental results, additive model used in L_9 (3^4) Taguchi OA is assumed to be the actual approximation model. On the contrary, if the predicted optimal conditions and the actual experimental conditions are quite different, it is indicated that the additive model is not assumed to be the actual approximation model. In addition, the design factor, selected performance characteristic and Taguchi OA are also inappropriate.

The aim of this study was to investigate the effect of structure design factors on the von mises stress of L-shaped corner dowel joint in pine by using finite element analysis and Taguchi method which can optimize the factor combination of furniture structure to reduce the cost and make in pine furniture structure be more stronger and robust to external disturbance factors.

MATERIALS AND METHODS

The pine samples used in this study was obtained from Beijing, China. Its moisture content was approximately 10 % and density was 0.55 g.cm^{-3}. The physical and mechanical properties tests were carried out in accordance with GB/T 15777-1995 and GB/T 1928-2009 in Technical Institute of Physics and Chemistry, CAS. Some physical and mechanical properties of pine utilized for method using Finite Element Analysis (FEA) were tested and are shown in Tab. 1. Test equipment: SANS CMT5000 MTS series microcomputer control electronic universal testing machine ; CryoLab system at temperature (4.2 K - 200 K).

Tab. 1: Physical and mechanical properties of pine used in FEM.

Density (g.cm^{-3})	Moisture content (%)	Bending strength (MPa)	Modulus of rigidity (MPa)			Modulus of elasticity (MPa)			Poisson's ratio		
ρ	MC	MOR	G_{LR}	G_{LT}	G_{RT}	E_L	E_R	E_T	μ_{LR}	μ_{LT}	μ_{RT}
0.55	10 %	83	1172	676	66	16300	573	1100	0.42	0.51	0.68

*L, R and T are the longitudinal, radial and tangential directions of wood.

In this study, three types of numerical models in 40×40×300 mm (radial × tangential × longitudinal) and 40×40×260 mm (radial × tangential × longitudinal) dimensions of L-shaped corner wooden dowel pins-joint were constructed with three different joint styles (90° Post on the Rail, 90° Post under the Rail, 45° Bevel Butt) in the PROE 5.0 software (Beijing, Shuohe Technology Co., Ltd.) as shown in Fig. 1a). Each test sample consists of two elements: Post and rail. In the experiments, pine wood dowels were used to connect two part of L-shaped corner. In order to simplify the analysis time, the joint is simplified to be interference fit joint without gule. For the joints without glue, hole diameter is nearly equal to tenon diameter and hole depth is approximately equal to half of the tenon length. Dowels were drilled to the center of section of post and rail in Fig. 1b) and the tenon gap is the distance between the axes of two dowels.

The simulation analysis of L-shaped corner wooden dowel pins joint in pine was carried out using ANSYS 10.0 software (China, Aonesoft company). According to the previous articles, the Finite Element model was built by ANSYS Solid Brick 8 node 185 element and meshed in triangle element size with 8 mm in width. To analyze the von mises stress of the corner-joint, the material properties in Tab. 1 were defined in preprocessor element type to simulate the orthotropic characteristic of wood in three perpendicular directions. For the post part of pine, the longitudinal axis is parallel to the Y-axis direction ; the radial axis R is parallel to the Z-axis direction; and the tangential axis T is perpendicular t Y-axis direction and Z-axis direction. While, for the rail part, the longitudinal axis is parallel to the X-axis direction ; the radial axis R is parallel to the Z-axis ; and the tangential axis T is parallel to the Y-axis. During the experiments, the external load value on the corner-joint was determined by furniture mechanics performance test of the China national standard (GB/T 10357.2-2013), the actual usage and ergonomic factors. The degree of freedom UX, UY, and UZ at the bottom of post was totally constrained. The vertical static load (1500 N) along the Y axis direction was applied to the end of middle node in the rail as shown in Fig. 1c).

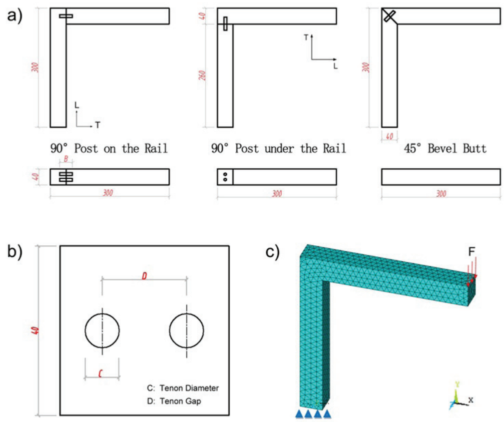

Fig. 1: Numerical models: a) Size sketch of pine L-shaped corner wooden dowel pins with three different structure styles; b) Size sketch of tenon diameter and tenon gap; c) Size sketch of load and constraint.

An analysis of the selected design factors, such as the values of the von mises stress allowed the level of deviation to be calculated to identify which changing factors were significant for the experiment. With four factors, each with three levels, the full experimental design requires $3^4 = 81$ possible combinations of tests. Carrying out such a large number of experiments for all the combinations is not reasonable. The Taguchi method makes use of an orthogonal array (OA) to examine the quality properties by reducing the number of experiments. In this study, structure style, tenon length, tenon diameter, and tenon gap were selected as four controllable design factors.

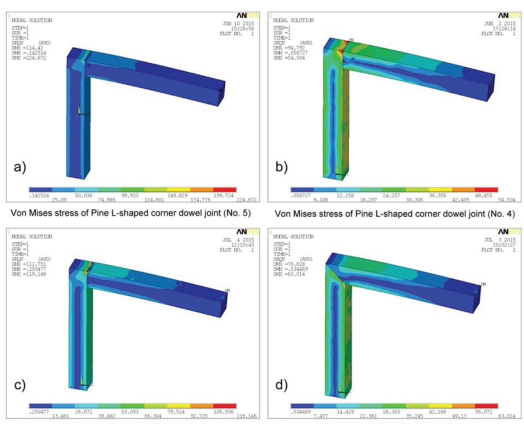

Fig. 2: Analysis of the finite element software: a) Von mises stress of pine L-shaped corner dowel joint (No. 5); b) Von mises stress of pine L-shaped corner dowel joint (No. 4); c) Initial condition of von mises stress; d) Optimal condition of von mises stress.

Tab. 2: Factors and values at different levels.

Factor / Level	Level1	Level 2	Level 3
Structure Style	90°Post on the Rail	90°Post under the Rail	45°Bevel Butt
Tenon Length	24 mm	32 mm	40 mm
Tenon Diameter	6 mm	8 mm	10 mm
Tenon Gap	10 mm	15 mm	20 mm

Tab. 3: L_9 (3^4) orthogonal array utilized in the experiment.

Factors /Trial No.	(A)	(B)	(C)	(D)	Von Mises stress (MPa)	S/N (dB)
1	90°Post on the Rail (1)	24 (1)	6 (1)	10 (1)	110.88	-40.90
2	90°Post on the Rail (1)	32 (2)	8 (2)	15 (2)	164.175	-44.31
3	90°Post on the Rail (1)	40 (3)	10 (3)	20 (3)	89.591	-39.05
4	90°Post under the Rail (2)	24 (1)	8 (2)	20 (3)	54.504	-34.73
5	90°Post under the Rail (2)	32 (2)	10 (3)	10 (1)	224.672	-47.03
6	90°Post under the Rail (2)	40 (3)	6 (1)	15 (2)	112.624	-41.03
7	45°Bevel Butt (3)	24 (1)	10 (3)	15 (2)	63.916	-36.11
8	45°Bevel Butt (3)	32 (2)	6 (1)	20 (3)	62.146	-35.87
9	45°Bevel Butt (3)	40 (3)	8 (2)	10 (1)	194.416	-45.77

These factors each at three levels were considered for the present study as shown in Tab. 2. Hence L_9 (3^4) Taguchi OA, as shown in Tab. 3 was chosen to study the four structural design factors of L-shaped corner wooden dowel pins joint in pine.

RESULTS AND DISCUSSION

Analysis of the finite element software

According to the ANSYS software analytical results, there are significant different effects of different design factors on the von Mises stress, which is shown in Tab. 3, Fig. 2a) shows that the highest von mises stress (224.672 MPa) of L-shaped corner dowel joint in pine was obtained in No. 5 trial, while the lowest (54.504 MPa) was acquired in No. 4 trial as shown in Fig. 2b). The maximum von mises stress in joints No. 5 trial was approximately 312 % higher than joints in No. 4 trial which was much above the value of bending strength of pine. For the joint in No. 5 trial, maximum von mises stress values occurred in the joint of the horizontal rail and vertical post. While, for the joint in No. 4 trial, maximum Von mises stress values was obtained in the parts of the tenon. In addition, von mises stress in No. 4 trial has much more gradually varied distribution than it in No. 5 trial.

Analysis of the S/N ratio

In this study, the results of the robustness for von mises stress obtained from finite element analysis for each trial were statistically analyzed by utiliziing Signal-to-Noise ratio (S/N) equations based on the lower the better characteristic shown in Eq. (1). The S/N ratio for von mises stress of structure style, tenon length, tenon diameter, and tenon gap for each nine trials are summarized in Tab. 3.

As shown in Tab. 3, the largest S/N ratio is about -34.73 dB in the No. 4 trial, while the lowest S/N ratio is nearly -47.03 dB in the No. 5 trial. The mean S/N ratio of 9 trials is about -40.53 dB.

Because the experimental design for the von mises stress and S/N ratio is orthogonal, it is possible to separate out the effect of each design factors at different levels. For instance, the mean S/N ratio for the structure style at three different levels can be calculated by averaging the S/N ratios for the experiments 1 to 3, 4 to 6, 7 to 9 respectively shown in Eqs.4, 5 and 6.

$$m_{A1} = \frac{1}{3}(\eta_1 + \eta_2 + \eta_3) \tag{4}$$

$$m_{A2} = \frac{1}{3}(\eta_4 + \eta_5 + \eta_6) \tag{5}$$

$$m_{A3} = \frac{1}{3}(\eta_7 + \eta_8 + \eta_9) \tag{6}$$

Based on the equation above, the η (dB) response table for each level of the design factors (structure style, tenon length, tenon diameter, and tenon gap) is created in the integrated manner and the η (dB) response values for von Mises stress at each level are given in Tab. 4. The total mean S/N ratio is about -40.49 dB.

Tab. 4: Mean S/N ratio for von mises stress at each level.

Symbol	Design factor	Level 1	Level 2	Level 3	Max-min
(A)	Structure Style	-41.42	-40.93	-39.25	2.17
(B)	Tenon Length	-37.25	-42.4	-41.95	5.15
©	Tenon Diameter	-39.27	-41.6	-40.73	2.33
(D)	Tenon Gap	-44.57	-40.48	-36.55	8.02
	Total mean S/N ratio =		-40.49		

The result of the ANOM of the S/N ratio for von mises stress at each level is drawn in Fig. 3. It was concluded that any change in the four design factors would lead to either improvement or degradation of von mises stress. For the three levels of factor A, the difference among the ratio values is small.

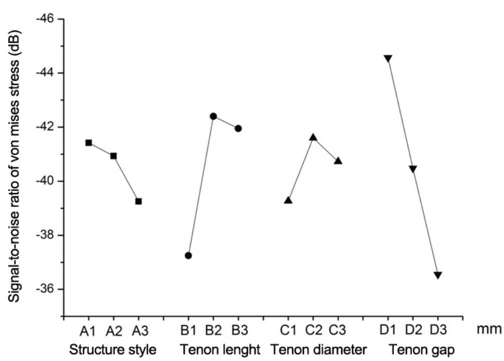

Fig. 3: Analysis of means (ANOM) of signal-to-noise ratio for von mises stress.

The S/N ratio value of A3 is the largest one. For the three levels of factor B and C, the S/N ratio value is decreasing initially with the increase of design factors, and then increasing with the further increase of design factors. For the three levels of factor D, the S/N ratio value is increasing with the increase of tenon gap. The S/N ratio value of D3 is the largest one among the levels. The structure design factors with the highest S/N ratio indicate a lower value of von mises stress. Hence, the optimal set of L-shaped corner dowel joint for von mises stress is acknowledged as A3 B1 C1 D3, which means that structure style is 45°bevel butt, tenon length is 24, tenon diameter is 6 and tenon gap is 20 mm.

Analysis of variance (ANOVA)

The purpose of the analysis of variance (ANOVA) is to identify the contribution of each factor to the variability in performance of the product (Gijo and Scaria 2010).

Firstly, the sum of square (SS) from the total mean S/N ratio ηm can be calculated as Eq. 7.

$$SS = \sum_{i=1}^{n} (\eta_i - \eta_m)^2 \tag{7}$$

where: n - the number of experiments in the orthogonal array,
η_i - the mean S/N ratio for the i -th experiment.

Each design factor has the mean of square (MS) which can be calculated by Eq. 8.

$$MS = \frac{SS}{DOF} \tag{8}$$

where: DOF - the number of degree of freedom in congruent with the design factors.

As a result of orthostichous orthogonal array in estimating error variation, the so-called freedom does not exist. Using the “Capture method”, the factors A and C which have lower squares are selected to estimate the average error variation in the analysis of variance.

Finally, the variance ratio (F-value) is obtained from the ratio of the mean square (MS) to the mean square error (SSe), which can be interpreted as the greater the effect on the structure performance characteristics owing to the major change of the design factors and traditionally used to determine the significance of each factor. The contribution percentage (%) is defined as a significance rate of design factors on the von mises stress.

Tab. 5 shows the ANOVA of S/N ratio for von mises stress. As can be seen from the data in Tab. 5, the contribution percentage for the factor A (structure style) is the lowest at 4.81 %.

Tab. 5: ANOVA of S/N ratio for von mises stress.

Factor	Sum of Squares (SS)	Degree of Freedom (DOF)	Mean of Squares (MS)	Variance Ratio (F-Value)	Percentage (%)
(A)	2.59	2	1.295	0.966418	4.81
(B)	16.27	2	8.135	6.070896	30.24
(C)	2.77	2	1.385	1.033582	5.15
(D)	32.16	2	16.08	12	59.78
Error	0	0	0		
Total	53.80	8	Note: At least 99 % confidence		
(Error)	(5.36)	(4)	(1.34)		

Meanwhile, the contribution percentages for the factor D (tenon gap) is the highest at 59.78 %. Thus, it was concluded that the factor D (tenon gap) has the most significant effect on the von mises stress in the concerned area, while the effect of the factor A (structure style) is negligible. Usually, when F>4, it means that the change of the design factors has a significant effect on the structure quality characteristics. From the analysis of variance, it can be concluded that factor B (tenon length) and factor C (tenon gap) are the significant design factors for affecting von mises stress. However, the variance ratio for the factor A is less than 1 which means structure style has a tiny effect on the structure performance characteristics for von mises stress.

Confirmation test

Confirmation test is the final and the most crucial step of Taguchi method. With the purpose of verifying whether the optimal result obtained in experiment is expected to improve, this test was carried out using the optimal design factors listed in Tab. 6.

Tab. 6: Result of confirmation test for von mises stress.

	Initial condition	Optimal condition		Improvement	IR
	ANSYS	Prediction	ANSYS		
von Mises stress (MPa)	119.146	63.014	63.014	56.132	47.11 %
S/N ratio (dB)	-41.52	-33.31	-35.99	5.53	13.32 %

Figs. 2c, 2d give the experimental results of initial condition and optimal condition for von mises stress using finite element software analysis. As shown in Fig. 2c, the highest von mises stress (119.146 MPa) of pine L-shaped corner wooden dowel pins joint appear in the top connection part of the corner. From Fig. 2d), we can find that the von mises stress (63.014 MPa) is located in the bottom of the corner rabbet which was much below the value of bending strength of pine. The improvement ratio (IR) is used to calculate the proportional ratio of Taguchi optimization results compared to the initial condition shown as Eq. 9.

$$\mathrm{IR} = \frac{P_{initial} - P_{optimal}}{P_{optimal}} \times 100 \qquad \% \tag{9}$$

The IR results were given in Tab. 6. According to Tab. 6, the IR for the von mises stress and the S/N ratio from the initial condition to the optimal condition is about 47.11 and the 13.32 %. From the above result we can come to the conclusion that Taguchi method using FEM can not only obviously reduce the von mises stress to improve the strength of the L-shaped corner dowel joint, but also effectively increase the S/N ratio to optimize the robustness of structure performance characteristics.

The purpose of the confirmation experiment in this study is to validate the optimal condition (A3 B1 C1 D3) that are suggested by the experiment which corresponded with the predicted value calculated by Eq. 10.

$$\eta_{\mathrm{opt}} = \eta_{\mathrm{m}} + \sum_{i=1}^{o} (\eta_{\mathrm{i}} - \eta_{\mathrm{m}}) \tag{10}$$

where: η_m - the total mean S/N ratio,
η_i- the mean S/N ratio at the optimal level,
o - the number of the main design parameters that affect the quality characteristic.

The S/N ratio for predicted optimal condition is calculated as:

$$\eta_{opt} = m + (m_{Ai} - m) + (m_{Bi} - m) + (m_{Ci} - m) + (m_{Di} - m) = m_{A3} + m_{B1} + m_{C1} + m_{D3} - 3m$$

However, the predicted optimal condition is commonly calculated using the -value with high percentage (%) to avoid producing higher improvement of predicted optimal condition than actual experimental optimization which leads to high-end prediction. Therefore, factor B and factor D are chosen to predict the S/N ratio of optimal condition. The S/N ratio for predicted optimal condition is calculated as:

$$\eta_{opt} = m + (m_{B1} - m) + (m_{D3} - m) = m_{B1} + m_{D3} - m$$

$$= -37.25 - 36.55 + 40.49 = -33.31 \text{dB} \tag{11}$$

As shown by the data in Tab. 6, the predicted value for S/N ratio is -33.31 dB. The experimental result by finite element analysis for S/N ratio is -35.99 dB. The result of the predicted optimal condition highly agrees in line with the actual experimental optimal condition which means that additive model using in Taguchi orthogonal test for prediction is as close as possible to the practical model. The orthogonal test and the design factors analyzed in this study are reasonable and effective.

Tab. 7: Comparison of experimental testing with numerical simulation.

Experiment test			**ANSYS simulation**		
Ultimate load Pmax	**Initial condition**	**Optimal condition**	**Von mises stress**	**Initial condition**	**Optimal condition**
(N)	1220	1450	(MPa)	119.146	63.014

The results obtained from ANSYS finite element simulation analysis were also compared with the results obtained from experimental test which shows in Tab. 7. The ultimate load in the L-shaped corner dowel Joint in optimal condition was greater than it in the initial condition which means the optimal structure of L- shaped joint in pine yields better strength and robustness than initial condition. The finite element method with Taguchi method was determined to be a general and suitable method when exact numerical calculations are used to check the loads imposed on structures, it can be used as a suitable, non-destructive technique for calculating structural strength at various times.

CONCLUSIONS

Overall, our study has revealed that finite element analysis with Taguchi method can be applied to optimize effectively the combination of structure design factor to maximize structure performance characteristic and minimize quality variation of L-shaped corner dowel joint in Pine, which saves time and money compared to traditional methodology.

Through the robust design based on L_9 (3^4) Taguchi OA, the optimal L-shaped corner dowel joint in pine is 45° Bevel Butt in structure style, 24 in tenon length, 6 in tenon diameter and 20 mm in tenon gap which have von mises stress at 63.014 MPa and S/N ratio at -35.99 dB. From the analysis of variance, it can be concluded that factor B (tenon length) and factor C (tenon gap) are the significant design factors for affecting von mises stress. There is a significant improvement from initial condition to optimal condition. The IR for von mises stress decreases by 47.11 while the S/N ratio increases by 13.32 % through robust design.

The results of the confirmation test confirm the effectiveness and efficiency of Taguchi method using FEA for optimizing the structure design factor with multiple performance characteristics. The orthogonal test and the design factors analyzed in this study are reasonable and effective.

This kind approach to optimize the structure strength and robustness of L-shaped corner dowel joint in pine using finite element and Taguchi orthogonal experimental method can be used for the other fast-growing wood and classical corner-joint in furniture structure in the future.

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