Verification and Further Study on Method of Measuring Contact Force Between Mortise and Tenon Joint

Wei-Lian Fu, Hui-Yuan Guan,* and Xin-Yi Zhang

This work verified the direct measuring method of the contact force and its relaxation behavior between mortise and tenon joints through withdrawal load resistance testing of T-shaped mortise-and-tenon joint specimens. Further, it also studied the influence of wood species, beech (*Fagus orientalis* Lipsky) and Mongolian Scots pine (*Pinus sylvestris* var. *mongolica*), interference fitness (0.1, 0.2, 0.3, and 0.4 mm; 0.2, 0.4, 0.6, and 0.8 mm), and wood grain orientation (radial, diagonal, and tangential) on the contact force and its relaxation. The results showed that the direct measuring method had good feasibility for measuring the contact force and its relaxation of the beech and it showed good feasibility on measuring initial contact force of pine. However, it showed low feasibility for measuring the relaxed contact force when the interference was 0.2 mm, but showed good feasibility on measuring the relaxed contact force with larger interference of pine. Interference fitness, wood grain orientation, and wood species had a significant effect on initial contact force and contact force after 5 h relaxation. This study showed feasibility and application scope of the method for direct measuring contact force and provided additional fundamental data to contribute to further study of the internal mechanical mechanism of mortise and tenon joints.

Keywords: Mortise-and-tenon joints; Contact force; Relaxation; Interference fitness; Grain orientation; Wood species

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INTRODUCTION

Extensive studies on the mechanical properties of mortise and tenon (M-T) joints using T-shaped or L-shaped samples have been investigated, mainly focusing on factors, such as wood species, tenon sizes, interference fit, and geometry of tenon. Withdrawal and bending load resistance are two common criteria to evaluate the strength of a M-T joint through experimental testing (Zhang and Eckelman 1993; Eckelman *et al.* 2004a,b; Tankut and Tankut 2005; Seraila *et al.* 2018) and finite element methods (FEM) (Gustafsson 1995; Kasal *et al.* 2016; Podskarbi and Smardzewski 2019; Hu and Liu 2020a,b) based on member level.

The mechanical strength of the M-T joint of wood product is mainly determined by contact force generated by the interference fitness and the bonding strength, as shown in Fig. 1. To further study the mechanical properties of the M-T joints, it is necessary to investigate on the above effects separately. However, the M-T joint has rarely been investigated because it was usually invisible. In this study, the authors' attention was mainly paid to the contact force.

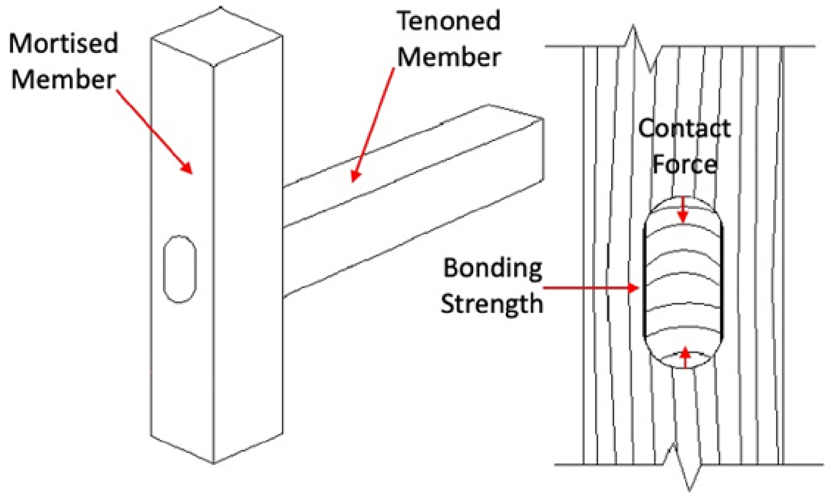

Fig. 1. Mechanical analysis of the mortise and tenon joints in actual state

It is difficult to measure the contact force directly between the mortise and tenon. Some studies tried to resolve this technique issue from different perspectives. Smardzewski (2008) analyzed the influence of wood species and adhesive type on the contact stress of the M-T joints of T-shaped samples by FEM. The result showed that the contact deformation of the mortise and tenon was caused by the bending of the tenon and the twist of the glue line. Zhang (2009) directly measured the contact force by compressing the separated wooden mortise and tenon. The study focused on the contact force of M-T joint with different tenon widths and interference fitness. However, the relaxation behavior M-T joint was not considered, which intensively affected the contact force between mortise and tenon. Hu *et al.* (2018, 2019) proposed a new method using the self-designed metal mortise and tenon moulds to determine the contact force between mortise and tenon and its 3-h relaxation behavior. The study focused on the contact force's relaxation prediction and did not verify this method in M-T joint member level. The method of direct measuring contact force (Hu *et al*. 2018, 2019) was verified on the M-T member level based on Coulomb's friction law. In addition, the contact force between mortis and tenon and its relaxation behaviors were further studied considering wood species, beech (*Fagus orientalis* Lipsky) and Mongolian Scots pine (*Pinus sylvestris* var. *mongolica*), interference fitness (0.1, 0.2, 0.3, and 0.4 mm; 0.2, 0.4, 0.6, and 0.8 mm), and wood grain orientation (radial, diagonal, and tangential). This study can help to further study the internal mechanical mechanism of the mortise and tenon joints and optimize the structural design of wood products.

EXPERIMENTAL

Materials

The wooden materials used in this study were beech (*Fagus orientalis* Lipsky) and Mongolian Scots pine (*Pinus sylvestris* var. *mongolica*). The air-dry densities of them were 0.66 g/cm^3 and 0.470 g/cm^3, respectively. The moisture contents of them were held at 11.25% and 11.73%, respectively, before and during the tests.

Configurations of Specimens

The machine used for processing the specimens was a computer numerical controlled (CNC) machine (WPC; ULI Corporation, Shanghai, China) with an accuracy of 0.01 mm. The basic dimensions of the oval tenon specimen were 35 mm × 35 mm × 16.8 mm (length × width × thickness), as shown in Fig. 2a. The basic dimensions of the T-shaped specimen are shown in Fig. 2b. To avoid the bonding strength of the tenon in thickness direction disturbing the measurement of the contact force and its relaxation on its width direction, a gap of 0.2 mm without glue was imposed on the thickness of the tenon of the T-shaped specimen. The size of tenon remained the same, while the magnitude of the interference was changed by altering the size of mortise in the T-shaped specimen, and “a” represented the magnitude of interference as shown in the Fig. 2b. The diagram of wood grain orientation of radial (R), diagonal (D), and tangential (T) orientations of a tenon in its width direction is shown in Fig. 3.

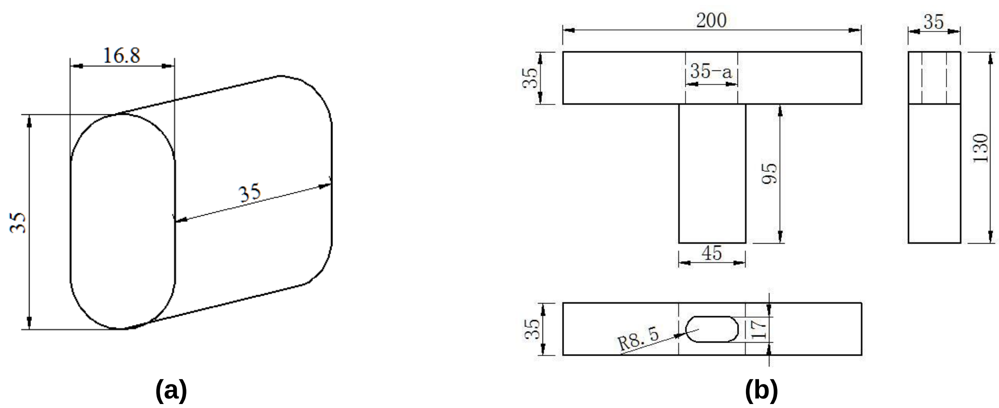

Fig. 2. Dimensions of specimens: (a) oval tenon and (b) T-shaped specimen; all units are in mm

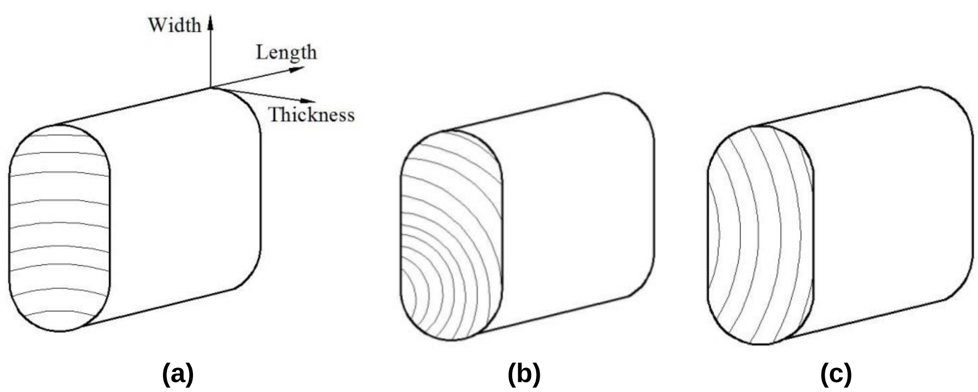

Fig. 3. Diagram of wood grain orientation of tenon in its width direction: (a) radial orientation; (b) diagonal orientation; (c) tangential orientation

Testing Methods

Direct measuring method of measuring the contact force and its relaxation

The method mainly referred to the force status of the M-T joints in the actual state, as shown in the Fig. 1, and it used the fixed distance compression function of the mechanical testing machine to measure the contact force and its relaxation of the mortise and tenon due to the interference fitness. It is common knowledge in the field of wood science that the longitudinal mechanical properties of the wood are much greater than the transverse (Chang and Hsu 2007; Chen *et al.* 2016; Hu and Zhang 2020); thus the study ignored the slight deformation of the longitudinal compression of mortise, so that the metal mortise moulds were used instead of the wooden mortise to compress the tenon at a fixed distance. The direct measuring method is shown in the Fig. 4.

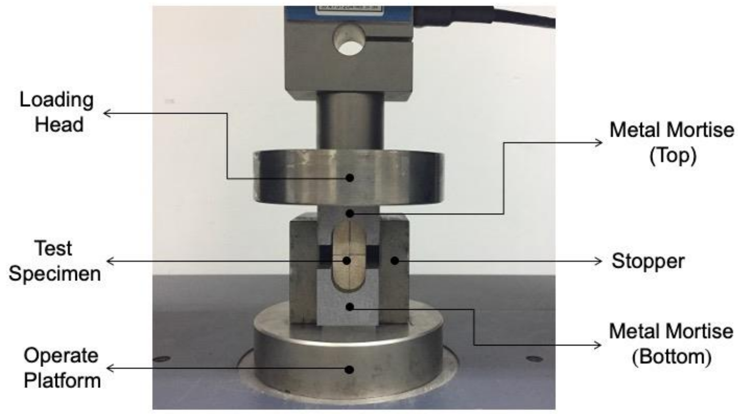

Fig. 4. Setup for test method for direct measuring contact force and its relaxation of M-T joints

The main equipment used in this test was the AG-X universal testing machine (Shimadzu Corporation, Kyoto, Japan). The steps in the test procedure can be listed as follows: 1) put the wooden tenon inside the metal mortise mould; 2) use the stopper as shown in Fig. 4 to limit the moulds to prevent the tenon from rotating, and the stopper must keep contact with the metal mortise mould without clamping force, thereby reducing experimental errors; 3) make the sensor force plate of the mechanical testing machine touch the top of the mould until a load of 10 N has been generated to ensure that the sensor pressure plate was in contact with the top metal mortise mould; 4) set up the program of the mechanical testing machine and compress the mortise mould at a fixed distance according to the interference fitness levels set in the study; the loading speed was 0.3 mm/min. Once the displacement of the loading head reached the specified distance (interference fitness), the loading head was kept at that distance. The contact force of the joints at this time was defined as the initial contact force; then the loading head was kept at this fixed distance for a period of time, and the contact force at this time was defined as the contact force after relaxation. To determine the suitable relaxation time of the contact force of the M-T joints under the direct measuring method, the contact force of the M-T joints made of beech wood under four level interferences was preliminarily tested for up to 12 h of relaxation, then deciding on the appropriate time to relax.

Verification test method of direct measuring contact force and its relaxation

To verify the feasibility and applicability scope of the direct measuring method about whether it can truly reflect the contact force and its relaxation of the M-T joints, the withdrawal tests were performed on T-shaped specimens of beech and Mongolian Scots pine.

Based on the Coulomb friction law, the friction force is proportional to the normal load. When applied to the withdrawal test of a T-shaped member, the upper and lower surfaces of tenon slide simultaneously, so the friction force at the upper and lower arcs of the ovel mortise and tenon joints is equal to the withdrawal load resistance of T-shaped member, and the contact force of the mortise and tenon joints is assumed to be the normal load (Seki *et al*. 2016). Therefore, the relationship between the withdrawal resistance force and the contact force in the actual state can be obtained using Eq. 1,

$$F_v = \frac{F_w}{2\mu} \tag{1}$$

where F_v is the contact force between mortise and tenon (N), F_w is the withdrawal load resistance (N), and μ is the friction coefficient. With reference to the study on the friction coefficient of beech (Hu and Guan 2017), the average value was 0.54; and the average value of friction coefficient of Mongolian Scots pine was 0.58 according to the same measuring method. The equipment used in the withdrawal test was the universal testing machine (Shimadzu Corporation, Kyoto, Japan), and the withdrawal speed was 10 mm/min, as shown in Fig. 5. One group of the assembled T-shaped specimens was immediately subjected to the withdrawal test, and the other group was left at room temperature and humidity (25 °C; 70%) for 5 h, and then the withdrawal test was conducted. Ultimately, the ultimate withdrawal load resistance was substituted into Eq. 1 to obtain the contact force of verification test F_v for comparison with the contact force value obtained by the direct measuring method.

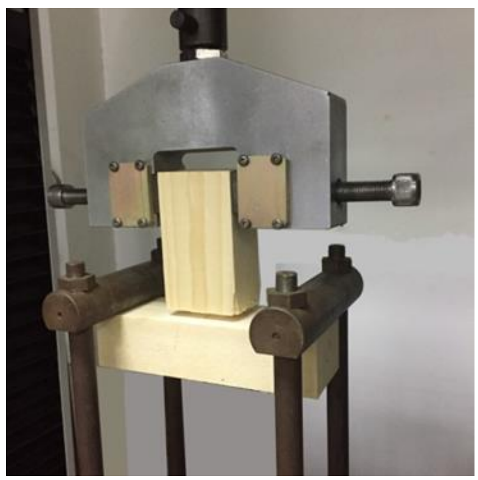

Fig. 5. Setup of measuring withdrawal load resistance

Experimental Design

Through the direct measuring method, the contact force and its 12 h relaxation of M-T joint on the radial grain orientation under the four levels of interference fitness (0.1, 0.2, 0.3, and 0.4 mm) of beech wood were measured. Each condition requires 5 tests; thus a total of 20 tests were needed. Through comparing the initial contact force (F_0), the relaxed contact force after 5 h (F_5), and the relaxed contact force after 12 h (F_{12}), the appropriate relaxation time was determined. Based on this, the direct measuring method about contact force and its relaxation of M-T joints in the radial grain orientation were verified according to the two wood species of beech and Mongolian Scots pine, and four levels of interference fitness, respectively (0.1, 0.2, 0.3, and 0.4 mm; 0.2, 0.4, 0.6, and 0.8 mm). The direct measuring experiment required five tests under each condition, for a total of 40 tests; the verification experiment required 10 tests under each condition, for a total of 160 tests.

Finally, the direct measuring method was used to further study the influence of interference fitness, wood grain orientation, and wood species on the contact force F_0 and

F_5 of the M-T joint. Moreover, the contact force retention S (%) was defined as in Eq. 2, and the influence of wood species on the contact force retention was also studied. Under each condition, five tests were required, for a total of 120 tests.

$$S = \frac{F_5}{F_0} \tag{2}$$

Statistical Analysis

First, the mean comparisons was performed using the protected least significant difference (LSD) multiple comparisons procedure to determine whether the initial contact force F_0, the contact force after 5 h relaxation F_5, and the contact force after 12 h relaxation F_{12} had any significant difference to determine a suitable relaxation time by the SPSS software (IBM Corporation, version 26, Armonk, USA). Then, the mean comparisons of contact force were performed according to four levels of interference fitness of beech and Mongolian Scots pine separately, to determine if the contact force before and after relaxation between calculated by verification test and corresponding contact force generated by direct measuring method had any significant difference. Additionally, the two-way analysis of variance (ANOVA) general linear model (GLM) procedure were performed to analyze the primary effects and their interaction in terms of interference fitness and wood grain orientation on F_0 and F_5 separately. Ultimately, for F_0 and F_5 at the interference fitness of 0.4 mm separately, the one-way ANOVA was performed to analyze the effects in terms of wood species. All statistical analyses were performed at the 5% significance level.

RESULTS AND DISCUSSION

Determination for the Suitable Time of Relaxation of Contact Force

Figure 6 shows the contact force relaxation curve for up to 12 h of the M-T joints made of beech wood according to four levels of interference fitness.

The findings were similar to the typical stress relaxation curve of wood that in the first phase the force declined rapidly then tend to flattening gradually, as reported in the research of Zhang *et al.* (2014). Table 1 shows the mean values of F_0, F_5, and F_{12} at different relaxation times and their mean comparisons results.

Table 1. Summary of Mean Contact Force Values at Different Relaxation Time

Interference Fitness	F_0	F_5	F_{12}
mm	N		
0.1	2007.34 (12.10) A	1294.85 (18.03) B	1181.17 (9.70) B
0.2	3088.74 (7.26) A	2277.54 (11.25) B	2174.81 (5.02) B
0.3	3505.73 (4.35) A	2477.49 (6.14) B	2371.78 (7.32) B
0.4	4118.55 (5.95) A	2778.05 (8.58) B	2655.56 (8.73) B

Note: The values in parenthesis are coefficient of variance (COV). The “N” represents the unit of newton for force. Two means in each row not followed by a common letter are significantly different one from another at the 5% significance level.

According to four levels of interference fitness, F_0 showed significant differences from F_5 and F_{12}, while F_5 and F_{12} had no significant difference at the 5% significance level. It suggested that the relaxation speed of the contact force after 5 h relaxation was at a low level. Therefore, considering the experimental time and efficiency comprehensively, 5 h were selected as the suitable relaxation time.

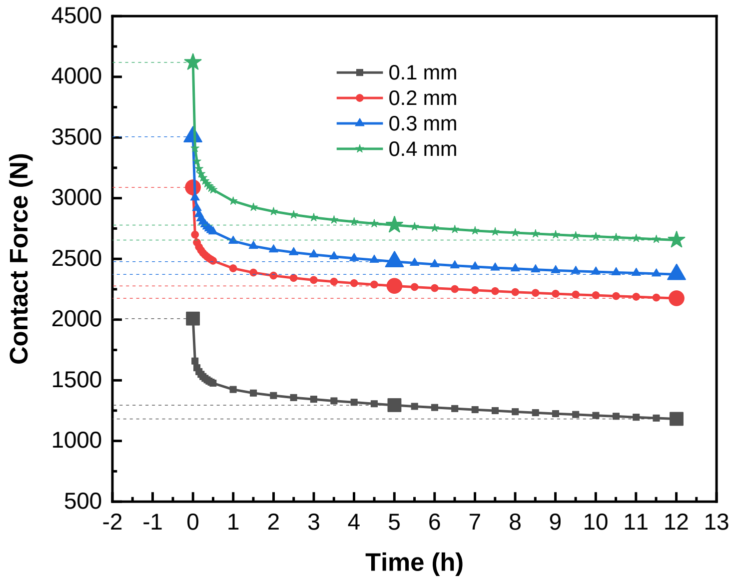

Fig. 6. Relaxation curve of the contact force of the M-T joints after 12 h

Analysis of Feasibility of Direct Measuring Method Before and After Relaxation

Tables 2 and 3 show the mean values of contact force before and after relaxation of beech and Mongolian Scots pine wood, respectively, according to four levels of interference fitness on the wood grain orientation of radial under direct measuring test and verified test, and the ratios of the contact force generated by direct measuring test to verified test.

Table 2. Summary of Beech Wood Mean Contact Force Values and Its Ratio Generated by Two Methods

Relaxation Stage	Interference Fitness (mm)	Contact Force by Direct Measuring Test (N)	Calculation Values by Verified Test (N)	Ratio (%)
Before Relaxation	0.1	1888.28 (3.29)A	1973.16 (6.56)A	0.957
	0.2	2932.80 (7.44)A	3105.32 (10.17)A	0.944
	0.3	4008.88 (4.12)A	4136.00 (7.95)A	0.969
	0.4	4383.92 (1.04)A	4634.84 (9.86)A	0.946
After Relaxation	0.1	1262.21 (18.19)A	1340.51 (5.49)A	0.942
	0.2	2298.84 (6.21)A	2351.80 (3.44)A	0.977
	0.3	3066.00 (8.08)A	3217.84 (9.73)A	0.953
	0.4	3185.87 (1.92)A	3552.34 (3.26)A	0.897
Note: The values in parenthesis are COV. Two means in each row not followed by a common letter are significantly different one from another at the 5% significance level.				

The comparisons in each row show that the direct measuring test results had no significant difference with the verified test at the 0.05 significance level, which indicated that the direct measuring method was feasible for measuring the contact force and its relaxation of M-T joints within this interference range (0.1 to 0.4 mm) of beech wood. The ratio of contact force before relaxation ranged from 0.944 to 0.969, and for after relaxation it ranged from 0.897 to 0.977. Those ratios indicated that the contact force generated by the verified test was higher than the direct measuring test. This was because the assembly error of the T-shaped specimen caused the contact friction area of M-T joints to increase. Thus, the calculated contact force value increased.

Table 3. Summary of Mongolian Scots Pine Wood Mean Contact Force Values and Its Ratios Generated by Two Methods

Relaxation Stage	Interference Fitness (mm)	Contact Force by Direct Measuring Test (N)	Calculation Values by Verified Test (N)	Ratio (%)
Before Relaxation	0.2	180.91 (7.23)A	183.44 (17.92)A	0.986
	0.4	559.98 (10.60)A	652.80 (19.79)A	0.858
	0.6	1288.78 (3.08)A	1301.92 (7.47)A	0.990
	0.8	1505.45 (3.52)A	1635.46 (10.03)A	0.921
After Relaxation	0.2	3.98 (0.14)A	35.10 (16.13)B	0.113
	0.4	107.46 (12.75)A	211.27 (18.10)A	0.509
	0.6	300.22 (12.47)A	432.48 (12.20)A	0.694
	0.8	353.95 (6.01)A	536.50 (7.28)A	0.660
Note: The values in parenthesis are COV. Two means in each row not followed by a common letter are significantly different one from another at the 5% significance level.				

Within the interference range of 0.4 to 0.8 mm, the comparison in each row showed that the direct measuring test had no significant difference with the verified test at the 0.05 significance level, which indicated that the direct measuring method was feasible for measuring the contact force and its relaxation within this interference range of Mongolian Scots pine wood.

At the 0.2 mm interference level, the comparison of contact force before relaxation between two tests showed no significant difference; however, for the relaxed contact force, the comparison showed that the direct measuring test result had significant difference with the verified test at the 0.05 significance level. Because under the direct measuring test, when the compression magnitude was low, the Mongolian Scots pine wood was at the low strain level of elastic region, so the initial contact force was low, and eventually the value relaxed to close to 0. This phenomenon was consistent with the research of Penneru *et al.* (2006) and Wakashima *et al.* (2019). However, the T-shaped specimen’s contact force relaxation speed was slower, which was caused by inevitable assembly error, whereby the tenon on thickness direction touched the mortise. The findings demonstrated that at low strain levels, the relaxation of contact force was greatly affected by assembly errors, and direct measuring methods could not reflect the true relaxation state of M-T joints. Meanwhile, the ratios of relaxed contact force ranged from 0.113 to 0.694. When compared with the ratios of relaxed contact force of beech wood, the ratio of Mongolian Scots pine wood was lower and more deviated from 1, which indicated that the direct measuring method had a relatively lower accuracy on measuring relaxed contact force of the M-T joint made of low density wood.

Analysis of the Influence of Interference Fitness, Wood Grain Orientation, and Wood Species on Contact Force and Its Relaxation of M-T Joints

Table 4 summarizes the ANOVA results obtained from the GLM procedure performed for each wood species of the two influence factors, which indicated that for M-T joints of beech and Mongolian Scots pine wood, the interference fitness ($p < 0.05$) and wood grain orientation ($p < 0.05$) had significant effects on the F_0 and F_5, but the interaction of the two factors had no significant effect on the F_0 and F_5.

Table 4. Summary of ANOVA Results Obtained From the GLM Performed on Two Factors for Contact Force

Wood Species	Sources	F_0		F_5	
		F-value	p-value	F-value	p-value
Beech	Interference fitness (A)	229.11	< 0.05	76.19	< 0.05
	Wood grain orientation (B)	136.10	< 0.05	222.19	< 0.05
	A × B	2.21	0.09	1.98	0.12
Mongolian Scots Pine	Interference fitness (A)	890.22	< 0.05	21.25	< 0.05
	Wood grain orientation (B)	128.00	< 0.05	12.53	< 0.05
	A × B	1.42	0.30	0.58	0.68

From the main effect analysis of beech wood, further checking the magnitudes of F-values of F_0 indicated that interference fitness had a larger F-value of 229.11 than wood grain orientation with an F-value of 136.10, which suggested that the significance of the interference was much stronger. However, for the F-value of F_5, the wood grain orientation had a larger F-value of 222.19 than interference fitness with an F-value of 76.19, which suggested that the wood grain orientation occupied a more significant effect on F_5. It was mainly due to the anisotropy of the wood caused by the different arrangement of the microstructure of wood affected the F_5.

From the analysis of the main effects of Mongolian Scots pine wood, further checking the magnitude of F-value of F_0 indicated that the interference had a larger F-value of 890.22 than wood grain orientation with an F-value of 128.00, which suggested that the significance of interference fitness was much stronger, the same as the beech wood's performance. For the F-value of F_5, the significance of the interference fitness was also stronger than the grain orientation; the similar result had been conducted by Kuwamura (2012), indicating that the anisotropy of Japanese cedar of softwood under compression had no obvious influence on its relaxation. But the difference in F-value of F_5 between the two factors was obviously reduced compared to F_0. This was mainly due to the comprehensive effect of the larger interference coverage of Mongolian Scots pine wood and the anisotropy of the wood.

Table 5 summarizes the ANOVA results, which indicated that the wood species ($p < 0.05$) had a significant effect on the F_0 and F_5.

Table 5. Summary of ANOVA Results Performed on One Factor for Contact Force

Source	F_0		F_5	
	F-value	p-value	F-value	p- value
Wood species	107.56	< 0.05	54.77	< 0.05

Echeniques-Manrique (1969) also concluded that the seven different tropical wood species had obvious effects on the relaxation in compression. This demonstrated that the wood density had a significant effect on contact force and its relaxation of M-T joint.

Figure 7 shows that under each wood species and wood grain orientation condition, the interference fitness had a positive relationship with the contact force before and after relaxation. Parts 7(a) and (b) of the figure show the trend of beech wood that when the interference increased, the values of F_0 and F_5 both increased under three levels of wood grain orientation, and both reached the peaks as the interference fitness at 0.4 mm. Moreover, as the magnitude of interference increased to 0.3, the increase in contact force slowed down. According to the research of Hu *et al.* (2007), its ultimate withdrawal resistance of T-shaped non-adhesive specimen first increased rapidly and then slowed down gradually along with the increasing of interference.

The internal mechanism of the curve change of withdrawal resistance was consistent with the curve change of contact force in this study, which, due to part of the tenon of M-T joints, was in a state of compression plastic deformation plateau period. It also could be observed that as the wood grain inclination relative to the horizontal direction increased from R to D to T, the values of F_0 and F_5 both decreased, which were consistent with Hu's (2018) research. This was because the beech wood had wider wood rays, so it showed higher yield strength in the radial grain orientation with the support effect of wood rays, and thus had better mechanical performance to resistant the relaxation of M-T joints.

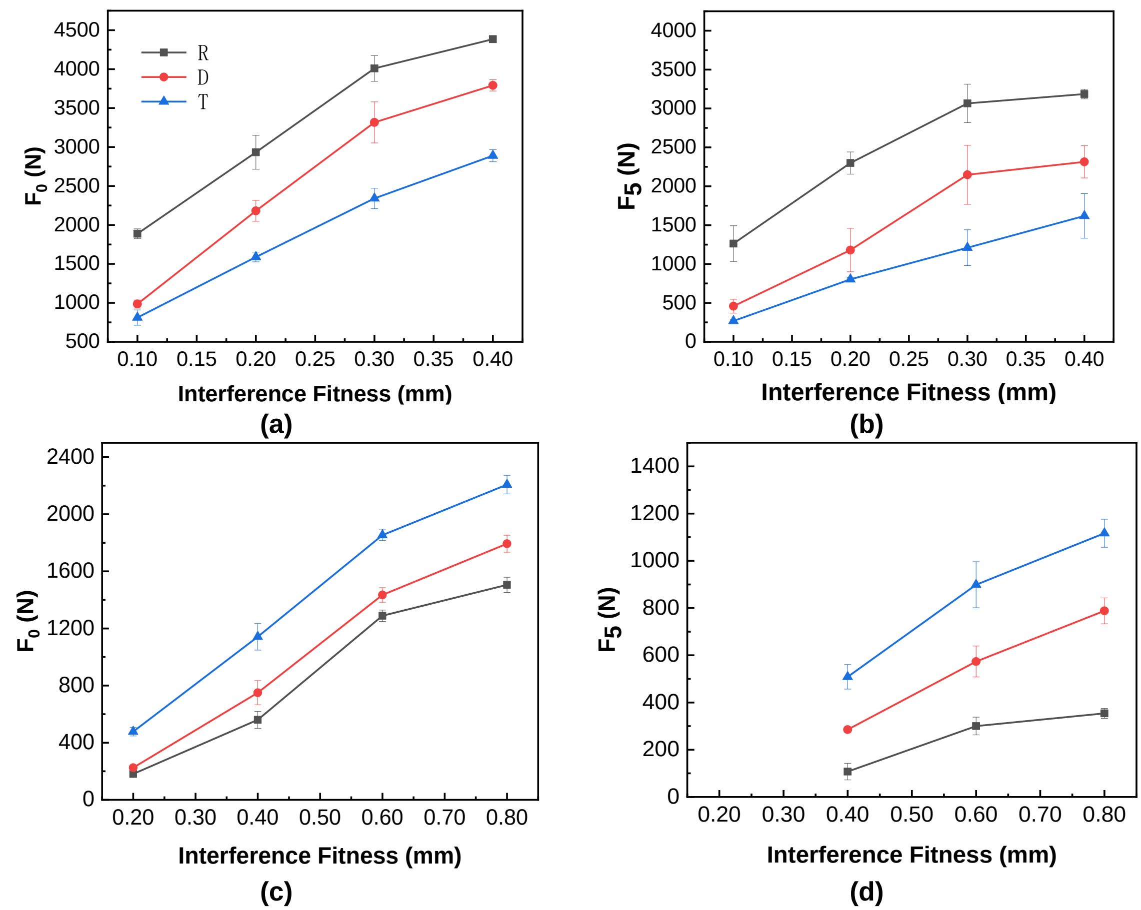

Fig. 7. The interference fitness-contact force curves of R, D, and T grain orientation: (a) F_0 of beech wood; (b) F_5 of beech wood; (c): F_0 of pine wood; (d): F_5 of pine wood

Figures 7(c) and (d) show the trend of Mongolian Scots pine wood that as the interference increasing, the values of F_0 and F_5 both increased under three levels of wood grain orientations and both reached the peaks as the interference at 0.8 mm. As the magnitude of interference increased to 0.6 mm, the increase in contact force also slowed down, which was consistent with the beech wood's performance. In addition, as the wood grain inclination relative to the horizontal direction increased from R to D to T, the values of F_5 and F_0 both increased. Because the Mongolian Scots pine wood is a coniferous wood, its material is relatively soft, especially the early wood component. Moreover, the difference between early and late wood was obvious, and the cell tissue was mainly composed of tracheids, and the proportion of wood rays was small (Cheng *et al.* 1985). Therefore, in the T grain orientation the late wood can play a good supporting role, so it showed better mechanical properties, and this performance was consistent with Aimene and Nairn's (2015) research.

Figure 8 shows the comparisons between beech wood and Mongolian Scots pine wood under the 0.4 mm interference fitness of F_0, F_5, and S separately, which indicated that the beech wood (high density) gave higher values of F_0, F_5, and S than Mongolian Scots pine wood (low density) in M-T joints. It was also reported by Wakashima *et al.* (2019) that wood relaxation under compression the greater the initial value of the compressive force, the greater the maintained force in the plastic region. The results suggested that the M-T joints of wood with higher density had higher initial mechanical strength and higher resistance to the relaxation of contact force than the wood with low density.

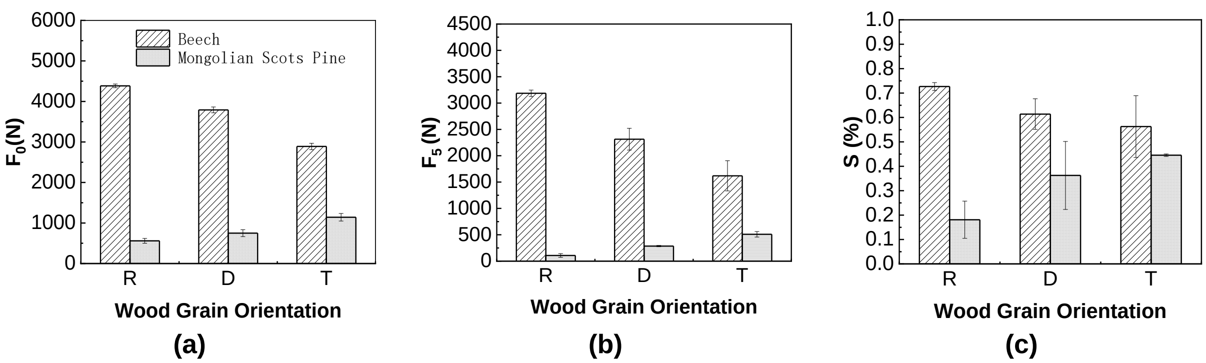

Fig. 8. The contact force and its retention of the M-T joints between beech and Mongolian Scots pine wood

Based on this method, further studies will focus on the influence mechanism of other factors on the contact force and its relaxation of mortise and tenon joints, such as moisture content or temperature. In addition, the study on optimizing the structure of wood products based on the influence mechanism will be performed.

CONCLUSIONS

1. For M-T joints of beech and Mongolian Scots pine wood separately, the comparison of the initial contact force between generated by direct measuring method and verified method according to four levels of interference fitness showed no significant difference ($p > 0.05$). The results suggested that the feasibility of using the direct measuring method to measure the initial contact force of the M-T joints of high or low density wood.

2. For M-T joints of beech wood according to four levels of interference fitness, the comparison of contact force after relaxation between generated by the direct measuring method and the verified method showed no significant difference ($p > 0.05$). The results suggested that the feasibility of using the direct measuring method to measure the relaxed contact force of the M-T joints of high density wood.
3. The comparison of contact force after relaxation between generated by direct measuring method and verified method of M-T joints of Mongolian Scots pine wood with the interference fitness of 0.2 mm showed significant difference ($p < 0.05$); but within the interference fitness of 0.4 to 0.8 mm, it showed no significant difference ($p > 0.05$). The results demonstrated its application scope and suggested that using the direct measuring method cannot reflect the actual state of relaxed contact force of M-T joint at low strain level of low-density wood.
4. The wood grain orientations and the interference fitness both had a significant effect on the initial contact force F_0 and the contact force after five hours F_5 of the M-T joints ($p < 0.05$). The beech and Mongolian Scots pine wood reached the peaks of F_0 and F_5 when the interference fitness was at 0.4 mm and 0.8 mm, respectively. Meanwhile, the F_0 and F_5 of R grain orientation were greater than the D and T grain orientation of the beech wood. However, the F_0 and F_5 of T grain orientation were greater than the D and R grain orientation of the Mongolian Scots pine wood.
5. Meanwhile, beech wood (high density) was higher than Mongolian Scots pine wood (low density) in F_0 and F_5 and contact force retention S of M-T joints. The results suggested that the wood with higher density has higher initial mechanical strength and higher resistance to relaxation of contact force of the M-T joints than the wood with low density.

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