Study on Screw-holding Ability of Three Screw Connections in Medium Density Fiberboard Components

Yiwan He, Sisi Chen and Ming Chen*
School of Forestry, Sichuan Agricultural University, Chengdu, China
*Corresponding author e-mail: chenming@sicau.edu.cn

Abstract. In this experiment, medium density fiberboard (MDF) was chosen as connection parts and orthogonal test method was used to study the influence of screw type, diameter of guide hole and screw penetration depth on screw-holding ability in MDF components. The results showed that the type of screw has no significant effect on the screw-holding ability, while the self-tapping screw with cross groove has the greatest effect, the diameter of the guide hole and the depth of the screw have significant effects on the strength of the screw-holding ability. Within a reasonable range, the larger the diameter of the guide hole and the deeper the screw penetration MDF has, the higher the anti-pulling force the screw get. In actual production, the strength of screw joint can be improved by increasing the diameter of guide hole and deepening the depth of screw properly.

1. Introduction

With the continuous improvement of national living standards, furniture ushered in a revolution in production inevitably and custom-made furniture arises at the historic moment. Compared with the original popular furniture design, customized furniture can be designed according to the size of the house, spatial structure, etc., to create a room style that belongs to consumers, so that consumers get higher visual enjoyment.

The study on furniture joint strength was carried out earlier in foreign countries, and the study mainly focused on the joint strength of furniture made of various wood based panels and joined by various joints [1]. Compared with some advanced countries abroad, the production of customized furniture in China started relatively late, and a relatively standardized system has not been formed. Many furniture products do not have specific standards to measure, and the processing system still needs to be improved and perfected [2].

Nails are a type of furniture connection, which wedlock two objects, or the position that fastens someone objects, belonging to one of more important hardware. So the installation standard of bolt and the mechanical property of screw also have the quality that cannot ignore to custom-made furniture. In addition, there are few papers and literatures on screw research, some of which are about the application of screws on bamboo, but the application of screws on customized plate furniture is basically not mentioned [3]. Therefore, the research on screws needs to be strengthened.

The main research objects of this study are several kinds of screws commonly used in customized furniture, including cross groove self-tapping countersunk head screws, cross groove round head self-tapping screws, and cross groove large flat head self-tapping screws. In this experiment, medium density
fiberboard (MDF) produced in Chengdu, Sichuan province was used as raw material and orthogonal test method was used to study the influence of screw type, the diameter of guide hole and screw penetration depth on nail holding force of MDF for furniture. The screw joint strength was optimized by considering the nail holding force of wood fiberboard for furniture.

2. Materials and methods

2.1. Materials
The test boards were taken from medium density fiberboard produced in Chengdu, Sichuan province (Xinlong Wood Industry GB11718-2009), which produced by Xinlong Wood Industry. The plate is 200mm, 50mm, 18mm. The density of plate is 600g/cm³.

2.2. Instruments and equipment
M-4100 Microcomputer control electronic universal mechanical testing machine (Regal Instruments Limited Company, Shenzhen), micrometer, screwdriver, electric drill.

2.3. Methods

2.3.1. Selection of influence factors. Through the analysis of the structural characteristics and strength formation of MDF furniture and the results of the preliminary experiment, the screw type, the diameter of guide hole and the depth of screw which have the greatest influence on the bonding strength are selected for investigation. Under the condition of the same surface, the type of screw, the diameter of guide hole and the depth of screw penetration determine the joint strength of MDF screws for furniture. The change characteristics of joint strength can be obtained effectively by taking it as an influence factor. The best combination provides reference for the design of MDF furniture screw structure.

2.3.2. Factor level selection. There are three kinds of screws: cross groove countersunk head self-tapping screw, cross groove round head self-tapping screw and cross groove large flat head self-tapping screw. See Table 1 for specific parameters and Table 2 for screw details.

| Table 1. Bolt parameters. |
|---------------------------|
| Screw type | Outer diameter | Type | Length | The national standard |
| Cross groove countersunk head self-tapping screw | 4 | H | 50 | GB 846 |
| Cross groove round head self-tapping screw | 4 | H | 50 | GB 845 |
| Cross groove large flat head self-tapping screw | 4 | H | 50 | JIS B 1122 |

| Table 2. Screw details. |
|-------------------------|
| Screw type | Schematic diagram | Head type | The material | Surface treatment |
| Cross groove countersunk head self-tapping screw |  | Countersunk head cross | 304 stainless steel | Stainless steel color |
| Cross groove round head self-tapping screw |  | Round head cross | 304 stainless steel | Stainless steel color |
| Cross groove large flat head self-tapping screw |  | Large flat head cross | 304 stainless steel | Stainless steel color |
For soft wood, the diameter of the guide hole is about 70% of the nominal diameter of the screw. For broadleaf timber, the diameter of the guide hole is about 90% of the nominal diameter of the screw [4]. Therefore, the diameter of the guide hole of the screw is determined at three levels: 2.85mm (71% of the nominal diameter of the screw), 3.00mm (75% of the nominal diameter of the screw) and 3.15mm (78% of the nominal diameter of the screw) (Figure 1).

The screw screws into the depth of the plate thickness general of about 3/4. Therefore, there are three levels of screw depth into the plate hole: 11.7mm (65% plate thickness), 14.4mm (80% plate thickness) and 17.1mm (95% plate thickness) (Figure 2).

2.3.3. Selection of assessment indicators. The strength of screw joint is mainly related to the pulling force of screw. Therefore, the anti-pulling force of screws on MDF is taken as the evaluation index.

2.3.4. Selection of orthogonal tables. There are three influence factors selected in the orthogonal experiment, and the level of each factor is taken as 3. There are 9 different combinations. One experiment was carried out for each combination, and there were 9 experiments. Orthogonal table L934 was used to design and make test specimens.

2.3.5. Method of determination of pulling resistance of screws on MDF. According to the national standard "test methods for physical and chemical properties of wood-based panels and decorative wood-based panels"(GB/ 17657-1999), the nail holding force test was conducted [5].

3. Results and analysis

3.1. The test results
The test scheme and test results of L934 are shown in Table 3. The variance analysis is shown in Table 4. As can be seen from Table 3, the anti-pulling force dispersion degree of screws on MDF board measured by nailing force test method is relatively large, with the maximum value up to 948.2N, the minimum value to 492.4N and the average value to 682.0N. As can be seen from Table.3 and Table 4, the extreme difference of screw-in depth factor is the largest, that is, the change of screw-in depth has a significant impact on the joint strength of bamboo wood furniture screws. The second is the diameter of the guide hole. The type of screw has the least effect on the joint strength of MDF furniture screw.

Three factors, such as screw type (A), guide hole diameter (B) and screw depth (C), should be considered simultaneously when designing the screw structure of MDF furniture and controlling the
joint strength of screw structure. The optimal design of screw joint structure was A1B3C3, that is, the screw type was self-tapping screw with cross groove round head, the diameter of guide hole was 3.15mm, and the depth of screw penetration was 17.1mm (Table 3).

Table 3. L_9^{3^4} Experimental plan and result.

| Test number | Screw type                              | Guide hole diameter /mm | The depth of the screw /mm | Pull-out force /N |
|-------------|-----------------------------------------|-------------------------|---------------------------|------------------|
| 1           | 1(Cross recessed round head self-tapping screw) | 1(2.85)                 | 1(11.7)                   | 562.2            |
| 2           | 1(Cross recessed round head self-tapping screw) | 2(3.00)                 | 2(14.4)                   | 781.4            |
| 3           | 1(Cross recessed round head self-tapping screw) | 3(3.15)                 | 3(17.1)                   | 948.2            |
| 4           | 2(Cross recessed countersunk head self-tapping screw) | 1(2.85)                 | 2(14.4)                   | 638.8            |
| 5           | 2(Cross recessed countersunk head self-tapping screw) | 2(3.00)                 | 3(17.1)                   | 756.0            |
| 6           | 2(Cross recessed countersunk head self-tapping screw) | 3(3.15)                 | 1(11.7)                   | 492.4            |
| 7           | 3(Cross groove large flat head self-tapping screw) | 1(2.85)                 | 3(17.1)                   | 742.0            |
| 8           | 3(Cross recessed countersunk head self-tapping screw) | 2(3.00)                 | 1(11.7)                   | 510.8            |
| 9           | 3(Cross recessed countersunk head self-tapping screw) | 3(3.15)                 | 2(14.4)                   | 706.6            |

K_1j \quad 2291.8 
K_2j \quad 1887.2 
K_3j \quad 1959.4 
K_{1j}/3 \quad 763.93 
K_{2j}/3 \quad 629.07 
K_{3j}/3 \quad 653.13 
R_j \quad 134.86 
K_{1j}^2 \quad 5252347.24 
K_{2j}^2 \quad 3561523.84 
K_{3j}^2 \quad 3839248.36 
Q_j \quad 4217706.48 
S_j \quad 31044.86 

Table 4. Variance analysis.

| Factors                              | Deviation square | Degrees of freedom | F-ratio | F-critical value |
|--------------------------------------|------------------|--------------------|---------|-----------------|
| Screw type                           | 31044.862        | 2                  | 0.546   | 10.900          |
| Guide hole diameter                  | 6951.742         | 2                  | 0.122   | 10.900          |
| The depth of the screw               | 132554.996       | 2                  | 2.332   | 10.900          |
| Error                                | 170551.600       | 6                  |         |                 |

3.2. Experimental analysis

3.2.1. The depth of the screw against the effect of pulling force. When the diameter of the guide hole is certain, the deeper the screw screws into the plate, the greater the anti-pulling force of the screw will be. This is because the deeper the screw screws into the plate, the more screw teeth into the guide hole, the larger the contact surfaces between the screw and the plate, and the greater the friction force, thus increasing the anti-pulling force of the screw [6]. For the same screw with a certain diameter of guide
hole, increasing the depth of screwing appropriately can improve the nail holding force of the screw on the plate [7].

3.2.2. The effects of screw type on pulling force. Different types of screws, including different head shape, different width of thread spacing, different depth of thread size, will have an impact on the anti-pull force of screws. However, from the results of the experiment, the type of screw has little influence on the size of the anti-pulling force of the screw. This is because the screw spacing of the three kinds of screws is 1.4mm, and the head shape and thread depth have little difference, so the experimental data change little. It can be seen from the figure that the national standard GB845 cross head tapping screw has the greatest anti-pull force.

3.2.3. Effect of holes diameter on screw type. The anti-pulling force of the screw increases with the diameter of the guide hole. This is because the smaller the diameter of the guide hole is, the more difficult the screw screws in, and the greater the extrusion pressure of the screw on the plate, which is easy to produce fiber uplift or split around the screw. Too small inlet hole is easy for screws to destroy the plate fiber, so the extrusion pressure of screws on the fiber around the inlet hole is too large. If the elastic ratio limit of the plate is exceeded, creep will occur and the anti-pulling force will decrease [8].

4. Conclusion
In this paper, orthogonal test method is used to optimize the structural design of MDF screw joint for furniture. The results showed that the type of screw had no significant effect on the strength of screw joint, while the diameter of guide hole and the depth of screw joint had significant effects on the strength of screw joint. The anti-pull-out force of the cross groove round head self-tapping screw is the largest, the difference of the anti-pull-out force between the cross groove large flat head self-tapping screw and the cross groove countersunk head self-tapping screw is not big, which is less than that of the cross groove round head self-tapping screw.

The anti-pulling force of cross groove large flat head self-tapping screw countersunk head self-tapping screw and cross groove round head self-tapping screw increased with the increase of the diameter of the guide hole. The diameter of guide hole of screw of MDF for furniture is 78% above
nominal diameter of screw more appropriate. For the same screw, when the diameter of the guide hole is certain, the deeper the screw screws into the plate depth, the greater the anti-pull force of the screw is.

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