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INVESTIGATION OF PERFORMANCE OF RECOMBINANT BAMBOO CHAIR THROUGH FINITE ELEMENT TECHNOLOGY

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ABSTRACT

Recombinant Bamboo is a newly bamboo material which breaks through the traditional processing mode, and its excellent physical properties can fully replace the wood widely used in furniture manufacturing. In this paper, take the classic back chair for example, in order to research the application of recombinant bamboo material in the furniture, using ANSYS finite element analysis software to compare the stress and deformation of recombinant bamboo, rosewood and elm under stress states. Meanwhile, in order to find out which leg shape is most suitable for the back chair of recombinant bamboo, the impact of the current mainstream three legs on the mechanical properties of the back chair is analyzed. Moreover, the parametric design method can work out the optimum size of legs and seat which are the most important design elements of back chair. This provides an evidence-based and effective method for furniture design.

KEYWORDS: Recombinant bamboo, back chair, finite element analysis, parameter optimization.

INTRODUCTION

China is a big country of the wood furniture industry, and the lack of timber resources is the main factor limiting the development of wooden furniture. However, China is recognized as "bamboo Kingdom", the bamboo species, bamboo forest area and stock volume all are the highest in the world. Back in the late 1970s and early 1980s, many scholars had put forward the plan of substituting wood for bamboo. Because of bamboo's short vegetative cycle this can ease the shortage problem of domestic timber supply. At the same time, this trend of thought also promoted rapidly the development of China's bamboo industry.

Recombinant bamboo is also known as heavy bamboo. It is a new composite bamboo material which is developed in recent years. And the processing characteristics breaks through the traditional machining mode, without damaging the bamboo fiber, compressed and glued bamboo ties or bamboo slices into a mold. This greatly improves the utilization of bamboo, and makes it possible to use the small diameter bamboo and poor quality materials. The processing technology of recombinant bamboo in Australia is the most advanced in the world. It bases on wood recombinant production technology and makes use of bamboo, residues in bamboo processing process and bamboo waste as raw materials. After rolling and kneading process, the raw material is treated into bamboo slices or bamboo ties which are without breakage in the transverse direction and with loose and cross connect in the longitudinal direction., And then through drying, sizing, forming and heat-pressing programs reorganization bamboo can be obtained (Li 2001). Due to its high strength and high density, and its texture and color like hardwood timber, recombinant bamboo is considered as a good engineering and furniture material.

In the past, most application of the bamboo furniture was mainly focused on bamboo's characteristics of press-resistance and better thermal insulation. Additional features of bamboo were not much applied in the original bamboo furniture. Recombinant bamboo lost a lot of characteristics of the original material. But its properties of physical and mechanical, corrosion resistance, shrinkage and swelling all have a number of advantages. Wood-based panel Department of Nanjing Forestry University was the first group to study the recombinant bamboo (Liu and Zhang 2008). This laboratory has successfully produced recombinant bamboo using *Pleioblastus* as raw material. It has the high modulus of rupture and modulus of elasticity. According to the test results of Nanjing Forestry University, recombinant bamboo structure is dense and uniform, its air-dry density is 1.00-1.20 cm^3, surface hardness is 174.5 MPa, end hardness is 165.3 MPa, thickness swelling (TS) rates is 1.64%, modulus of rupture is 130-185 MPa, dry shrinkage in the width direction is 2.23%, and the impact strength is up to 175 $KJ \cdot m^{-2}$.

However, the application of recombinant bamboo in furniture industry is still in the initial stage of exploration, although it has excellent physical properties and easy processing, environmental performance and other characteristics. It was initially used in producing floor board, and its applications and research in furniture area have been more and more recently. Because of its physical, chemical and mechanical features, recombinant bamboo has been concerned by the furniture designers.

There were few researches about applications of recombinant bamboo in furniture, the main research achievements is new Chinese furniture study of the Nanjing Forestry University. Professor Zhang Binyuan at Nanjing Forestry University presented the recombinant bamboo has broad application prospects that it can become a new and high-quality sustainable material in the furniture manufactures according to its characteristics (Zhang 2008). Lin Jumei at Nanjing Forestry University studied the application of recombinant bamboo in furniture manufacturing adaptability. She indicated that recombinant bamboo has reached excellent grade in chipping, sanding, drilling, sawing and finishing processing, and made a preliminary study on the recombinant bamboo applied to Ming-style furniture design and manufacture. Guan et al. (2009) studied the drying shrinkage and wet expansion characteristics of recombinant bamboo, the results showed that the recombinant bamboo's drying shrinkage coefficient was similar to teak, lower than several common furniture woods such as oak, and with strong directivity at the similar densities (Guan 2009). In term of the furniture strength, Huang and Wu (2011) researched round-tenon, oval-tenon and screw engagement of recombinant bamboo furniture respectively. Many other scholars also have done some studies about tensile, compressive, flexural and bearing properties of recombinant bamboo furniture.

Overall, the application of recombinant bamboo in furniture is still in its infancy. Although it can replace the wood material to be widely used in the manufacture of furniture because of its excellent material properties, different material attribute will cause unexpected impacts in design and processing.

MATERIAL AND METHODS

In conventional furniture structure design, theoretical calculation or empirical value methods were the main ways, there is not an accurate design analysis method that can be easily mastered and operated. Current research in the furniture structural mechanics mainly includes experimental analysis and finite element analysis (TC41-SAC GB/T 1939 - 2009). At present, the mechanical property tests of furniture mainly are the overall destructive tests. This results in a waste of raw materials and energy.

Experimental analysis of structural strength mostly is parametric studies of joining mode or mortise and tenon joint structure. With the development of finite element software functions, finite element analysis method gradually is applied to the structural design of furniture. In the analysis of furniture structural strength, finite element method mainly is applied to analyze the whole or partial static load, impact load, drop test or optimize the local fragile point for a typical furniture or its components, The feasibility of finite element has been proved.

FEM (Finite Element Method) is an efficient numerical method for solving differential equations. Its basic theoretical idea is that continuous geometry is discretized into a finite number of cells and set a finite number of nodes in each cell. And the continuum is considered as the aggregate made up of a group of cells in the node connection. Mathematical approximation method is used to simulate the real physical system. And different units are interconnected via nodes. The displacement, stress, strain, etc. under the action of force can be calculated via these nodes. Real system with unlimited number of unknowns can be approximated using a limited number of unknowns.

In the process of furniture design, FEM can be used as a fast and effective simulation method. It can analyze the complex framework structures stress and strain; make furniture components shape and size to meet all functional, aesthetic and strength requirements. Simulation software is used to calculate and design the structural strength of the product and computer-aided design software is used for structural optimization. Mechanical analysis can be done by the simulations for the complex materials and models under different loads. And the simulations are repeatable. Use software to analyze the structure of physical model and optimize the model parameters for each section of the product. This can provide us a new idea for quickly and effectively selecting the appearance size and shape of furniture components.

Verification of the recombinant bamboo application in the chair

Parameters of three materials

In this study, take the chair for example, applications of recombinant bamboo in furniture is studied by comparing recombinant bamboo, rosewood, elm three materials. Because there are no relevant standards and specifications of the mechanical properties of recombinant bamboo in China, its physical and mechanical properties are tested using the test methods of wood. And this is easy to compare recombinant bamboo with the wood.

Compression strength perpendicular to grain of recombinant bamboo is tested according to the test method of that of wood in GB/T 1939-2009; TC41-SAC GB/T 1939 - 2009. Tensile strength parallel to grain of recombinant bamboo is tested according to the test method of that of wood in TC41-SACGB/T1938-2009. Compression strength parallel to grain of recombinant bamboo is tested according to the test method of that of wood in GB/T1935-2009. Modulus of elasticity and Poisson's ratio in compressive parallel to grain of recombinant bamboo are tested with strain gauge method in GB/T1943-2009. The average test values of three materials can be obtained by repeated measures. Comparing the three materials, it is found that the compression strength parallel to gain is significantly greater than compression strength perpendicular to grain for wood. And compressive strength of wood substantially increases with the increasing density. The difference between bending strength of wood in tangential direction and that in radial direction is small. And the bending strength of wood also substantially increases with the increasing density. Compression strength perpendicular to grain of recombinant bamboo is stronger obviously than that of wood. And the difference between the compressive strength of recombinant bamboo in perpendicular direction and that in parallel direction is much smaller than that of elm or rosewood. These also show that recombinant bamboo is more suitable than others for the bidirectional stress situations. Simulation parameters of the three materials are shown in Tab. 1.

Tab. 1: Modulus of elasticity, Poisson's ratio, shear modulus of three materials.

Material	Density ($g \cdot cm^{-3}$)	E1 (MPa)	E2 (MPa)	E3 (MPa)	μ12	μ13	μ23	G12	G13	G23
Rosewood	1.05	18627	2677	1293	0.371	0.641	0.788	402	359	323
Elm	0.67	7472	674	163	0.474	0.516	0.661	145	110	96
Recombinant bamboo	1.11	15466	3007	1204	0.440	0.304	0.336	1347	823	567

The analysis of the chair load

Chairs will be subjected to three type loads: static load, cyclic load and impact load. In this study, effects of the static load on chairs for different materials are primarily compared. The value and location of loads, as well as its mode of action also directly affect the structure of the furniture. Structural design of the chair should have sufficient strength to meet the daily use conditions and occasional stress situation. The selection of design loads is according to the structure weight of chairs and their safety. It is too small or too large will cause unnecessary material waste. However, there is no definite design load standard of wood chair. Therefore, the size of load is determined firstly referring to the state standard (GB 10357.3-89). And then the load can be increased properly according to the special application of ergonomic in the use of furniture and the special circumstances in actual use. It is more scientific and reasonable to consider the load values and load points from many aspects.

Geometry model

In this paper, the classic back chair is chosen. Its geometry model is shown in Fig. 1. The back chair consists of forelegs, hind legs, seat face, back, support column and several other components. Its connection structure is mainly the mortise and ten on joints of Chinese furniture.

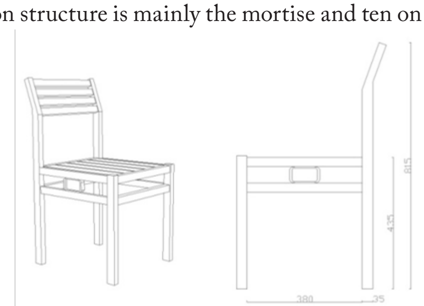

Fig. 1: Prototype and size of the back chair.

The overall width is 420 mm, the depth is 415 mm, and the overall height is 815 mm. And the seat face high is 435 mm and the sectional side length of square leg is 35 mm. During normal use, the maximum static load on chair seat surface is body weight. The max weight load of people should be selected in this research. According to the national standard GB10000-88 "China adult body size" the weights of 95% Chinese adult men aged 26-35 are 74 kg and aged 36-60 are 78 kg. After comprehensive consideration, the weight is chosen as 75 kg in this study, namely the load is 735N.

Loading mode

According to the national standard GB 10357.3-89, the test is divided into four working conditions. Considering the misuse under special circumstances and three grade standards of test level of international practice, the load value is increased to 1500 N.

Condition 1 the loads of seat surface: the chair is supported by the ground, its movement in the Y-axis direction is restricted, the load is 1500 N, and the load point is at the center line of the seat and 100 mm away from the seat surface. It is shown on the left in Fig. 2.

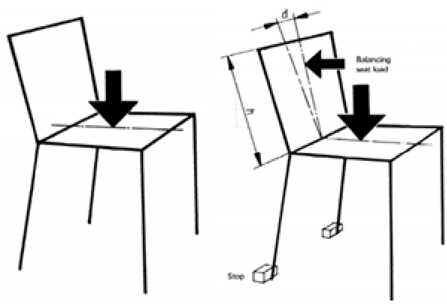

Fig. 2: Static load constraint conditions of the seat face and backrest in national standard GB 1035 7.3-89.

Condition 2 the loads of chair backrest: the ends of back legs are constrained and have the translational degrees of freedom in the Z-axis positive direction and the rotational degrees of freedom around the X- axis. Front legs are constrained from translational degrees of freedom in downward direction of the

Y- axis, but rotational degrees of freedom around the X-axis still are retained. Backrest load point is on the longitudinal axis of backrest and 300 mm away from the upper end of the backrest, its value is 500 N. And an 1100N balancing load is imposed. It is shown on the right of Fig. 2;

Condition 3 the front loads of legs: Translational degrees of freedom of back legs in Y-axis direction are restricted, and the degrees of freedom in all directions on the front legs are constrained. The balanced load at the seat face is 1100 N. And a 500N load is imposed on the intermediate position of back edge of seat face and the direction of load is horizontal and forward. It is shown on the left of Fig. 3.

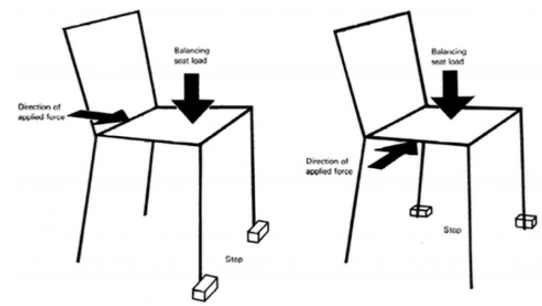

Fig. 3: The front and side static load constraint conditions of the chair legs in national standard GB 10357.3-89.

Condition 4 the lateral loads of legs: Translational degrees of freedom are constrained on the Y axis, and an 1100N balancing load is imposed on the seat face; and then all degrees of freedom of the legs in one side of chair are constrained. And in the other side a 500N load is applied on the middle position of the seat surface. It is shown on the right of Fig. 3.

RESULTS AND DISCUSSION

Results of the finite element analysis

The 3-D geometrical model of furniture is built by using PROE software. According the seamless connection between PROE and ANSYS, the model is imported into ANSYS software to calculate and analyze.

In this study, the static loads of the back chair model need to be calculated and analyzed. The mechanics properties of back chair respectively made of rosewood; elm and recombinant bamboo are analyzed and compared. In order to simulate more realistically the characteristics of anisotropic materials in axial direction, radial direction and tangential direction, the selected cell types must be able to correctly simulate the three-dimensional entity of orthotropic material, and the element nodes should have the freedom of movement in three-dimensional space. Therefore, the ANSYS unit is selected as the SOLID45 unit, which is set as a model body with the movement degree of freedom in three-dimensional space. Whether the recombinant bamboo can meet the requirements of wood furniture can be verified through the comparison of back chair of three materials.

The version of software is ANSYS15.0; surface grid size is 5mm; the number of grid nodes is 310491; the number of grid cells is 66827. According to the material parameters mentioned above, the calculation results of the three materials are separately shown in Tabs. 2, 3, 4.

Contrasting the maximum stress and maximum deformation of four cases, it is shown that recombinant bamboo has the smallest deformation under the same conditions. The order of the deformation from small to large is recombinant bamboo, rosewood wood and elm. Rosewood`s maximum stress is the smallest, and the order of maximum stress from small to large is rosewood, elm and recombinant bamboo. It is shown that the material performances of elm and rosewood are similar, and their deformations are in direct proportion with stress. Characteristics of recombinant bamboo are different to that of wood materials under the same conditions. Its deformation is relatively small but the stress is relatively large. Through the comprehensive judgment, the reconstituted bamboo is not only in conformity with the requirements of furniture manufacture, but also has less stress deformation than the ordinary wood materials. However it is easy to break when it is subjected to the impact because of its larger stress.

Tab. 2: Calculation results of rosewood.

Rosewood	Maximum stress (MPa)	Maximum stress position	Maximum deformation (mm)	Maximum deformation position
Seat surface load	5.5511	junction of seat surface and legs	0.92148	seat surface
Backrest load	8.963	junction of seat surface and back legs	2.2099	ride brain of backrest
The front load of legs	6.3364	constraint position of front legs	0.95828	junction of backrest and seat surface
Thelatera load of legs	6.9057	legs in no-load direction	1.0412	Backplane of ride brain

Tab. 3: Calculation results of elm.

Elm	Maximum stress (MP)	Maximum stress position	Maximum deformation (mm)	Maximum deformation position
Seat surface load	6.6834	junction of seat surface and legs	2.7593	seat surface
Backrest load	9.3666	junction of seat surface and back legs	6.0746	ride brain of backrest
The front load of legs	5.7288	constraint position of front legs	2.7856	junction of backrest and seat surface
The lateral load of legs	7.0538	legs in no-load direction	3.1732	Backplane of ride brain

Tab. 4: Calculation results of recombinant bamboo.

Recombinant bamboo	Maximum stress (MPa)	Maximum stress position	Maximum deformation (mm)	Maximum deformation position
Seat surface load	6.4391	junction of seat surface and legs	0.79143	seat surface
Backrest load	10.536	junction of seat surface and back legs	1.9046	ride brain of backrest
The front load of legs	7.0669	constraint position of front legs	0.73125	junction of backrest and seat surface
The lateral load of legs	7.687	legs in no-load direction	0.96587	Backplane of ride brain

In the above analysis, it is confirmed that the recombinant bamboo material is suitable to be used as the furniture material instead of wood. But the shape of the chair legs could affect the deformation of the recombinant bamboo chair. This paper analyzes the deformation of the recombinant bamboo chairs with three different legs (Wang et al. 2014).

In this part, two aspects which are cross section shape and the vertical direction of the chair legs are analyzed. First, selecting the existing common cross section shape which is square section and circular section chair legs as the research objects, hoping can study the force and deformation of recombinant bamboo legs on different cross section shapes and on the different sizes of cross section of legs. Second, in the same cross section of recombinant bamboo chair legs, the study is focused on the stress and deformation of chair legs when the chair legs are vertical to the ground and in a certain angle with the ground (Ramsauer 1971, Chung and Eckelman 1995).

Comparative studies of different cross sections

Taking the forces of front legs as the judgment criterion of the analysis, first the translational degrees of freedom on Y axial are constrained. And a 2000N balance load is applied on the seat surface. Then all the degrees of freedom of front legs are constrained. And a 750N load is applied on the middle position of back edge of seat surface along horizontal and forward direction. The shapes of the chair legs are respectively square, small round and round. The diameter of the small round leg is equal to the side length of the square leg, and the diameter of round leg is equal to the diagonal line length of the square leg. Tab. 5 shows the comparison of the stresses and deformations of the square, small round and round chair legs. It is found that the biggest stress points of these three legs are in the same position under the same load. The contact area of chair leg is inverse proportion to deformation at the same shape. Round chair legs have the smallest deformation, the value is 0.71509 mm. And the structure strength of square chair legs is much better than that of the round. The maximum stress of the square legs is 10.049MPa, which is the smallest in the three groups of contrast data. And stresses of the square legs are obviously smaller than those of the round legs.

Tab. 5: Calculation results of square, small round and round chair legs.

Recombinant bamboo	Maximum stress (MPa)	Maximum deformation (mm)	Maximum stress of front legs (MPa)
Square legs	10.049	0.85371	6.5217
Small round legs	12.939	0.90696	9.3308
Round leg	13.2	0.71509	13.2

Comparative study of different angles

The calculation results of the square chair legs and the trapezoidal chair legs are shown in Tab. 6. Trapezoidal chair leg has a certain angle between the leg and the vertical direction, but the bottom of the trapezoid legs is the same as the square bottom of the square chair legs. The loads of chair are divided into two kinds. The front loads of legs: Balance load on the seat surface is 2000N. Then all the degrees of freedom of the front legs are constrained. A 750N load is applied to the middle position of the back edge of seat surface. The direction of load is horizontal and forward. The lateral loads of legs: Balance load on the seat surface is 2000N. Then all the degrees of freedom of legs in one side of chair are constrained. And in the other side a load of 750N is applied to on middle position of the seat surface. The direction of load is from the constrained side to the non-constrained side.

From the calculation results of the square chair legs and the trapezoidal chair legs, it can be found that the stresses of square chair legs in all directions are smaller than that of the trapezoidal chair legs under the same loads. Forward deformation of the trapezoidal chair legs are smaller than that of the square legs, but lateral deformation of the square chair legs is smaller than that of the trapezoidal chair legs. It can be known that the trapezoidal leg with an oblique angle in the forward direction can effectively reduce the deformation. Generally speaking, the structure strength of square chair legs is better than that of the trapezoidal chair legs, which indicates that legs perpendicular to the ground is better than that oblique to the ground. Meanwhile, in the actual design and production, square legs can make full use of the material strength for the raw material with same size. And square chair legs are much easier to process.

Tab. 6: Calculation results of square and trapezoidal chair legs.

Recombinant bamboo	Forward maximum stress (MPa)	Forward maximum deformation (mm)	Maximum stress of front legs (MPa)	Lateral maximum stress (MPa)	Lateral maximum deformation (mm)
Square legs	10.049	0.85371	6.5217	8.1001	1.2338
Trapezoidal legs	13.924	0.79039	8.1282	12.174	1.2917

Parameter optimization of recombinant bamboo chair

The optimization design that was sprung up in 20^{th} 60's is a technique to determine the optimal design for our products. The so-called "optimal design" is that a design must meet all design requirements and the expenditure must be minimal. Usually optimization design will be used to optimize the size during the design process of furniture. Because it can meet the basic function and simultaneously help us to save material and processing costs (Crisfield 1997).

To achieve the "optimal design", a parameter optimization process must go through design variables, state variables, objective function, design sequence, reasonable design, analysis files, and cyclic iteration. As the analysis above, under the same conditions, the recombinant bamboo has a smaller deformation and a larger stress compared with rosewood and elm. We will optimize the size of the recombinant bamboo chair leg by constraining the stress. The above cross-sectional shape of the legs is square, and its cross-sectional area is 35×35 mm. In order to expand the range of optimization, we increase cross-sectional area to 40×40 mm, and the shape of cross-section will not change. We parameterize the sizes of chair in the PROE. It is named DS_ # as prefix and imported into ANSYS Workbench. The force load is applied on the legs in front side of chair, such as the working condition 3: The translational degrees of freedom of back legs in Y-axis direction are constrained, and the degrees of freedom of the front legs in all directions also are constrained. A balance load of 1100 N is applied on the seat surface, and a load of 500 N is applied on the middle position of the back edge of seat surface along horizontal and forward direction.

In the parameter optimization process, we will use the meshing method above to generate mesh. And the maximum stress of chair is defined as optimization condition, the seven parameters of DS_E, DS_F, DS_I, DS_J, DS_B, DS_C, and DS_O are chosen as optimization objectives. Where DS_O means seat surface thickness, and it ranges 20 - 30 mm, the other optimization ranges are all set as 20 - 45mm. The optimization conditions are set as the max stress and minimum quality. The Latin Hypercube Sampling method is used for design of experiments (DOE). And 80 design points are generated for comparison in Fig. 4.

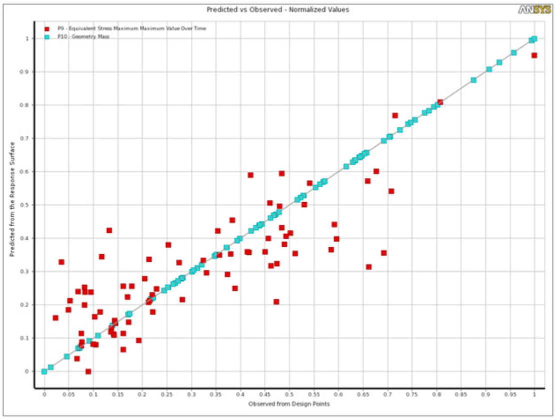

Fig. 4: 80 design points.

By the calculation, the optimal solution is obtained as follow: the cross-sectional area is 32.5x32.5 mm and the thickness of the seat surface is 25 mm. When the cross-sectional area and the thickness of seat surface are optimal, maximum stress of the chair is 6.0294 MPa and quality is 11.185 kg. Compared to the original design, the optimal solution makes the width of chair leg and the thickness of the seat surface reduce by 2.5 and 5mm respectively.

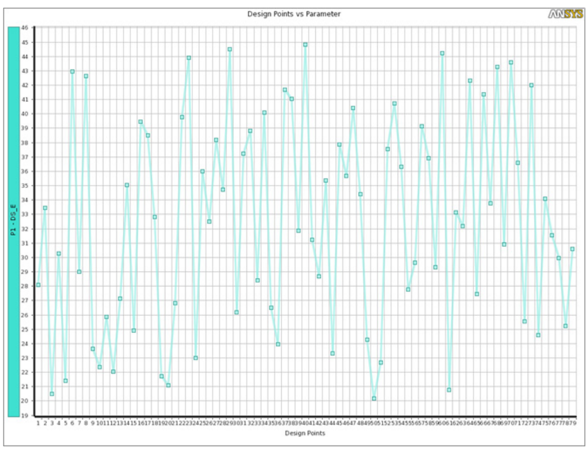

Fig. 5: Local sensitivity.

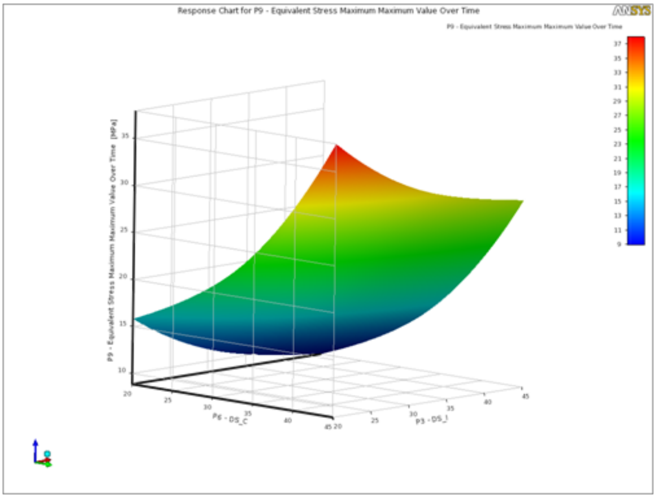

Fig. 6: 3D Response chart.

Fig. 5 shows the sensitivities of input parameter DS_C and DS_I, where DS_C means cross-section of the front leg and DS_I means cross-section of the back leg. The Sensitivities in Fig. 5 is consistent with the actual situation. Fig. 6 shows the maximum stress will be the minimum when DS_C and DS_I are approximately equal.

CONCLUSIONS

The promotion of the recombinant bamboo furniture is an effective way to solve the shortage of wood. Recombinant bamboo itself not only is better than ordinary timber in mechanical strength, grain color is beautiful, and its process ability is similar to hardwood. Therefore it is an ideal material for furniture manufacture in China.

The shape of chair leg has a significant influence on the stress and deformation of the chair under the stress state. The stress and deformation are inversely proportional to the cross-sectional area of the chair leg. So the smaller area is and the greater stress and deformation are. The performance of the square chair legs is stronger than that of the round legs, and the performance of vertical chair legs is stronger than that of the chair legs with an oblique angle.

Parameter optimization can help the designer to adjust the chair shape and obtain the optimal scale.

At the same time, using finite element analysis method the furniture in the condition of load can be analyzed. The performance of furniture products can be predicted and the weakness in the design is also found out. What is more important is that the results obtained by ANSYS are coincided with the theoretical calculation and the actual situation. Compared with the destructive experiments which create huge waste of resources, using the finite element analysis method to analyze the strength of furniture has many advantages, such as easy adjustment of parameters, quick calculation, accurate calculation, intuitionistic effect and so on. Researchers can understand the structural strength of each part of the furniture by analysis results, so as to provide a full range of reference standards for the next step of furniture optimization design and reduce the design cost. This provides a new way of thinking for the development of modern furniture design methods.

REFERENCES

1. Crisfield, M.A., 1997: Nonlinear finite element analysis of solids and structures, John Wiley and Sons, 32 pp.
2. Chung, W.Y., Eckelman, C.A., 1995: Finite elements analysis application to the structural design of the frame type furniture, Journal of Korean Wood Science Technology 23(3): 8-15.
3. Guan, M., Lin, J., Yhu, Zi., 2009> Shrinkage and swelling properties of recombinat bamboo, Journal bamboo Research 28(3): 38-41 (in Chinese).
4. Huang, S.Y., Wu, Z.H., 2011: Study on joint property of oval-tenon of reconstituted bamboo furniture, China Forest Products Industry 25(2): 40-44
5. ISO 7173-1989: Furniture-Chair and stools-determination of strength and durability
6. Li, Q., 2001: Prospect for re-combined bamboo timber, Journal of Bamboo Research 20(1):76-80.
7. Liu, X., Zhang, Z.F., 2013: Study on the design of outdoor furniture made of recombinant bamboo, Applied Mechanic Material 397-400:907-910.
8. Ramsauer, D., 1971: Application of finite element analysis to design a piece of furniture, Russian Physics Journal 14:1153-1155
9. TC41-SAC GB/T 1939-2009: Method of testing in compression perpendicular to grain of wood.
10. TC41-SAC GB/T 1938-2009: Standard test method for tensile strength of wood.
11. TC41-SAC GB/T 1935-2009: Standard test tethod for compressive strength of wood grain.
12. TC41-SAC GB/T 1943-2009: Method for determination of the modulus of elasticity in compression perpendicular to grain of wood.
13. Zhang, B., 2008: Recombined bamboo, a new sustainable development material for good quality furniture, Furniture 164(3): 64-66.
14. Zhang, J., et al., 2012: Analysis of compressive and tensile mechanical properties of recombinant bamboo, Nanjing Forestry University 36(4): 107-111.
15. Wang, Y., et al., 2014: Finite element method of corner joints in steel-framed structures under fire conditions. Applied Mechanical Materials 578-579: 407-411.
16. Zhang, J., et al., 2012: Analysis of compressive and tensile mechanical properties of recombinant bamboo, Nanjing Forestry University 36(4): 107-111.

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