Investigation of Parameter Optimization of Recombinant Bamboo 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, through the parametric design method to 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.

1 RECOMBINANT BAMBOO

1.1 Introduction of recombinant bamboo

Recombinant bamboo is also known as heavy bamboo. It is a modern composite which developed in recent years, and its processing characteristics breaks through the traditional machining mode, without damaging the bamboo fiber, compressed bamboo ties or bamboo slices into a mold. This greatly improves the utilization of bamboo, and makes it possible to use dwarf 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, bamboo processing residues and bamboo waste as raw materials. After rolling and kneading process, the raw material is treated into a transverse not broken and longitudinal loose and cross linked bamboo slices or bamboo ties, and then processed by drying, sizing, forming and heat-pressing programs becoming reorganization bamboo. 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.

1.2 The research status of recombinant bamboo furniture

In the past, most application of the bamboo furniture was mainly focused on bamboo’s characteristics of press-resistance and better insulation. Additional features of bamboo are not much reflected 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 have a couple of advantages. 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 protection and other characteristics. It was initially used in producing floor, and its application sand areas of research have been used more and more recently. Because of its physical, chemical and mechanical features, recombinant bamboo has been concerned by furniture designers.

2 RESEARCH METHODS OF FURNITURE STRUCTURE

2.1 Experimental methods

In conventional furniture structure design, theoretical or empirical methods were the main ways; there is not any 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. Current furniture tests of mechanical proper ties mainly on the overall destructive tests, resulting in a waste of raw materials and energy.

Experimental Analysis of structural strength mostly is parametric studies of joining mode tenon and mortise structure. With the development of finite element software functions, finite element analysis gradually applied to the structural design of furniture. China started late on the application of finite element method analysis of furniture structural strength, mainly targeted at furniture components or a whole typical furniture, applying finite element method to analyze static load, impact load, drop of
its entirety or parts, proved the feasibility of finite element, or the local fragile point optimization.

2.2 Finite element method

FEM (Finite Element Method) is an efficient numerical method for solving differential equations. Continuous geometry is discretized into a finite number of units and set a finite number of nodes in each cell, so that the continuum as a set of units at a node connected to the aggregate of its basic theoretical ideas. Mathematical approximation method to simulate the real physical system, interconnected via nodes between different units, these nodes can be calculated in the left the force used under displacement, stress, strain, etc., to approximate a limited number of unknowns unlimited amount of real unknown system.

In the process of furniture design, FEM can be used as a fast and effective method for simulation of complex framework structures stress and strain analysis, make furniture components shape and size to meet all functional, aesthetic and strength requirements. Computer-aided engineering software is used to calculate the structural strength of the product designed and computer-aided design software is used for structural optimization. Mechanical analysis for complex materials and models to simulate different forms of load is a repeatable process. Using software to analyze the structure of solid modeling to optimize the model parameters for each section of the product would provide us a new idea for quickly and effectively selecting the furniture components appearance of size and shape.

3 RECOMBINANT BAMBOO MATERIAL PARAMETER

3.1 Parameters of material

Research goal of this article is a classic back chair, by studying the parameter optimization of the chair leg stress and strain in the stress state. By limiting the maximum pressure of the chair leg and the weight of the chair, the parametric design of the chair leg is studied. Recombinant simulation parameters bamboo material was obtained, which is shown in Table 1, by standard recombinant bamboo material relevant material parameters of the experiment.

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>RECOMBINANT BAMBOO</th>
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<tbody>
<tr>
<td>DENSITY (g/cm³)</td>
<td>1.11</td>
</tr>
<tr>
<td>E1(MPa)</td>
<td>15466</td>
</tr>
<tr>
<td>E2(MPa)</td>
<td>3007</td>
</tr>
<tr>
<td>E3(MPa)</td>
<td>1204</td>
</tr>
</tbody>
</table>

μ12 0.440
μ13 0.304
μ23 0.336
G12 1347
G13 823
G23 567

3.2 The analysis method of the chair load

In this paper, choosing the classic back chair as physical simulation contrast objects shown in Figure 1, there are forelegs, hind legs, sit face, back, support column and several other components. Its connection structure of furniture is mainly of Chinese mortise and tenon joints. The overall width is 420mm, the depth is 415mm, overall height is 815mm, and sitting face high is 435mm and square leg sectional side length is 35mm. During normal use, the maximum static load on chair seat surface is body weight. According to the national standard GB10000-88 "China adult body size," taking into account the weight load of people should be selected larger, taking95th-percentile standard. According to it, Chinese adult men aged 26-35 weighing 74kg, 36-60 weighing 78kg. After comprehensive consideration, in this study, taking75kg, the load is 735N.

This test according to the national standard GB 10357.3-89 divided into two working condition, considering the misuse under special circumstances, as well as international practice test three levels standard ,the load value increased to 1500N.

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

Condition 2 chair legs on the front side load: Translational degrees of freedom of hind legs in Y-axis direction are restricted, and the degree of freedom in all directions on the front side of the hind legs is bound. The balanced load at the seat is 1100N; a force on intermediate position of seat back edge along the horizontal forward is 500N load. As shown on the left of Figure 2.

Table 1. Modulus of elasticity, Poisson's ratio, shear modulus.
Results of the finite element analysis

The 3D geometrical model of furniture was built by using PROE software, according the seamless connection between PROE and ANSYS, imports the model in to the finite element analysis software of ANSYS to calculate and analyze.

For more realistic simulation of the materials presented anisotropic characteristics, the selected cell types must be able to correctly simulate the three-dimensional entity of the orthotropic material, and the element nodes should have the freedom of movement. Therefore, the ANSYS unit is selected as the SOLID45 unit, which is set as a model body with three-dimensional space movement degree of freedom. 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. As shown on Figure 3.

Parameter Optimization of Recombinant Bamboo Chair

The optimization design that was sprung up in 20th60's is a technique to determine the optimal design for our products. The so-called "optimal design" refers to a design must meet all design requirements, and the expenditure must be minimum. Usually parameter optimization will be used in optimizing the design of furniture, because it can help us to save material and processing costs, and meet the basic function simultaneously.

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 loop. To achieve the "optimal design", here we will optimize size of the recombinant bamboo chair leg to reduce the stress. The above cross-sectional shape of the legs is square, and its cross-sectional area is 35mmX35mm. In order to expand the scope of optimization, we change cross-sectional area to 40mmx40mm, and the shape of cross-section will not change. We parameterized the sizes of chair in the pro-E, and used the name DS_# as prefix to import to ANSYS workbench. The force load was applied on the legs front side, such as the operating condition2: Constraint the rear legs' translational degrees of freedom of Y-axis direction, and constraint all the degrees of freedom of the front legs; applying a normal force 1100N on the seat; applying a horizontal force 500N at the middle of the back side of the seat.

In the parameter optimization process, we will use the meshing method above to generate mesh. And defining the maximum stress of chair as object variable, DS_E, DS_F, DS_I, DS_J, DS_B, DS_C, DS_O as input parameters, which DS_O means sit face thickness, and it ranges 20mm-30mm, the rest is set the scope of 20mm-45mm. The object variable is the stress and quality. The Latin Hypercube Sampling method was used for design of experiments (DOE), and 80 design points were generated for comparison in Figure 4.

After the calculation, the optimal solution was provided, and when the cross-sectional area was 32.5mmx32.5mm, and the thickness of the seat was 25mm, maximum stress of the chair was 6.0294MPa and quality was 11.185kg. Compared to the original design, the optimal solution made the width of chair leg reduce by 2.5mm, and the thickness of the seat reduce by 5mm.

Figure 5 is the sensitivities chart 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 rear leg. The Sensitivities chart in is line with the actual situation. Figure 6 shows that When DS_C and DS_I are approximately equal, the maximum stress will be minimum.
5 CONCLUSIONS

The promotion of the reorganization of 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 workability is similar to hardwood, which is an ideal material for furniture making in China.

Parameter optimization can help designer to adjust chair shape to the optimal scale. At the same time, using finite element analysis method to analyze the furniture in the condition of load can predict the performance of furniture products and find out the weakness in the design, 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, direct effect and so on. Researchers can understand each part of the furniture structural strength by analyzing, so as to provide a full range of reference standards for the next step of furniture optimization design, and reduce the design cost which provides a new way of thinking for the development of modern furniture design methods.

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