Finite element analysis of bending performance on polyurethane composite panel

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Abstract: The finite element analysis model of polyurethane composite panel (simply named PCP) is established by using ABAQUS software. In view of the PCPs made of different thickness of surface board, their bending performance is carried out on finite element analysis, and the load-deflection curves which come from it are compared with the experimental results. The results show that the values between finite element analysis and experiment agree well with each other. It can be deduced that the established finite element model is fit to simulate the bending test of PCPs. The simulation not only has certain reference significance to the optimal design for the bending performance of PCPs, but also to the choice of PCPs in the practical project.

1. Introduction

Polyurethane composite panel is a kind of sandwich board which polyurethane rigid foam is firmly bonded between two layers of surface board made of metal or non-metal which is in good fire resistance. As a type of new building material in engineering, polyurethane composite panels are widely used for external building envelope and internal partitions in prefabricated houses. They provide good function performance for building, for instance, sound insulation, thermal insulation, heat preservation, fire prevention and so on. In addition, polyurethane composite panel not only responds to the policy of housing industrialization in China, realizing mass production in the factory and high degree of prefabrication assembly in construction site, but also become a important development direction of the construction industry, beneficially promoting the construction industrialization in our country.

At present, the application of composite panel is mainly being focused on the sandwich plate of metal surface, which of non-metal surface is still in the stage of development in our country. The main research methods of polyurethane composite board are classical analytical method, approximation method and finite element method. Based on sandwich panels of the metal surface plate, Qin Peicheng made a research on constitutive relation of polyurethane foam material. Yu Min studied deformation mechanism and design formula of sandwich panels with finite element method [1-2]. The formula for calculating deflection of sandwich panels with metal surface plate was put forward by Davies[3]. On the basis of the predecessor's work, the bending performance of sandwich plate which made of non-metal surface studied more are Structural Insulated Panels with wood surface board[4-5]. Li Hongqiao analyzed the compressive performance of polyurethane composite board with fiber cement board[6].The finite element method was widely used in the research of composite plates by Styles and others, which provides a reference for the finite element study of sandwich panel[7].

In conclusion, the research of sandwich panels with non-metal surfaces has got a certain achievement. However, there are few researches based on the composite panel made of fiber cement
surface board and polyurethane core, and there are extremely few studies using finite element method on comparing the bending performance of metal surface sandwich panels with non-metal surface sandwich panels. Therefore, it is pretty necessary to carry out studying on the polyurethane composite panels.

This paper based on the bending experiments[8], which polyurethane composite panels were applied a concentrated load in the middle, establishes research model for the bending performance of polyurethane composite panels with different thickness and materials of surface board by means of the finite element software ABAQUS, and compares calculating results with the test results, which not only has certain reference significance to the optimal design for the flexural performance of polyurethane composite panel, but also to the choice of panels in the practical engineering projects.

2. Experiment

2.1. Introduction of Experiment

The polyurethane composite panels involved in this paper are provided by Wanhua Energy-saving Building Materials Co., LTD. Polyurethane composite panels make full use of the good cohesion of polyurethane foam firmly bonded to the surface board which is fiber cement surface board or color steel plate. According to the test scheme[8], the bending test of sandwich panels is carried out on the YZS-500 hydraulic testing machine. The specimen is supported by two high strength steel columns and the load is applied to the middle of the composite panel with cuboid steel beam. The moment in the middle of specimen is \( M = \frac{PL}{4} \), the values of the load applied and the mid-span deflection of the panels are measured by the sensor and the displacement meters respectively. Finally, the curve of load-deflection is plotted. Figure.1 shows the simplified experiment device.

2.2. Experiment results

Figure.2 shows mid-span load-deflection curves of bending test for the polyurethane composite panels in four groups. It can be seen from the figure that the stiffness of PCP-2 is higher and bearing capacity is stronger than PCP-1, because of the fiber cement board of PCP-2 being thicker than PCP-1. Similarly, compared with PCP-3, PCP-4 has thicker color steel surface plate, so it accordingly presents higher stiffness and stronger bearing capacity. Comparing PCP-3 with PCP-2, it is found that the bearing capacity of PCP whose lower surface board is color steel plate is stronger than PCP whose lower surface board is fiber cement board.

In conclusion, the thicker the surface plate of sandwich boards is, the higher the stiffness and the stronger bearing capacity become. On the same conditions, the color steel plate could be used to improve the ductility of polyurethane composite panels.

Figure 1. Experiment device.

Figure 2. Load-deflection curve.
3. Finite element model

3.1. Three dimensional finite element model

Table 1 shows the size on four groups of specimens. Although thickness of surface boards or polyurethane composite panels is different from each other, the length and the width are same. Figure 3 shows the finite element model established in accordance with the practical specimen.

| PCP Groups | Plane Size /mm | Span /mm | Thickness of Upper Surface Board /mm | Thickness of Lower Surface Board /mm | Thickness of Polyurethane /mm |
|------------|----------------|----------|---------------------------------------|--------------------------------------|-------------------------------|
| PCP-1      | 2000×1000      | 1800     | 6board A                              | 6board A                             | 68                            |
| PCP-2      | 2000×1000      | 1800     | 8board A                              | 8board A                             | 64                            |
| PCP-3      | 2000×1000      | 1800     | 8board A                              | 0.5board B                           | 71.5                          |
| PCP-4      | 2000×1000      | 1800     | 10board A                             | 0.5board B                           | 69.5                          |

Note: board A means fiber cement board, board B means color steel plate.

The bearings are 15mm diameter circular columns, and the steel beam applying load is a 15mm×15mm×1000mm cuboid. Solid element of C3D8R is used to establish the model of surface board and polyurethane core. The bearings and the steel beam applying load in the finite element model are set as rigid body. The displacement load is applied by steel beam at the rate of 2mm/min. Except U3 and rotational displacement, the rigid body displacement are restrained (the direction should is shown in Figure 3). Boundary conditions of finite element model correspond to experiments. The model is simplified as a simply supported beam, which is depicted as Figure 4. Because there is no degumming during experiments, tie as an ideal contact is used between panel and core material. The contact between steel beam and sandwich board as well as between bearings and composite panel is surface to surface, and finite sliding is also considered. Grid of the model established in finite element software is divided into hexahedron.

According to design standard in China [9], the mid-span deflection of PCPs is not allowed to exceed L/200, the letter of “L” standing for the span of PCPs. It can be concluded from table 2 that the failure load is three or four times as large as the load corresponding with f=L/200. Figure 2 illustrates the curves of load-deflection performed in elastic stage before deflection reaching L/200. Therefore, this paper only study the elastic stage of PCPS.

| Number of PCPs | Load (f= L/200 )/KN | Destruction Load/KN |
|----------------|----------------------|----------------------|
| PCP-1          | 3.22                 | 9.83                 |
| PCP-2          | 3.63                 | 12.39                |
| PCP-3          | 3.12                 | 13.94                |
| PCP-4          | 3.27                 | 14.65                |

3.2. Materials description

Materials parameters involved in this paper are based on the performance test report on wall materials
produced by Wanhua Energy-saving Building Materials Co., LTD. Because the materials used in the experiment were not the same batch, the material parameters used as analyzing are different slightly. It should be noted that the problem mentioned above have little influence on the accuracy of the analysis. The specific parameters are shown in table 3.

| Materials          | Elasticity Modulus E/Mpa | Yield Strength fy/Mpa | Poisson Ratio μ |
|--------------------|--------------------------|-----------------------|----------------|
| Polyurethane PCP1/2 | 10                       | 0.142                 | 0.3            |
| Polyurethane PCP3/4 | 8                        | 0.142                 | 0.3            |
| Fiber cement board | 3200                     | —                     | 0.22           |
| color steel plate  | 210000                   | 345                   | 0.3            |

Note: “-“ means not applicable.

4. Results and discussion

4.1. Stress nephogram

Figure 5 shows the strain nephogram for PCP1/PCP2 in finite element method. It’s found that the model established can simulate the deformation of specimens well. Figure. (a) is the stress cloud of a whole PCP. It can be seen that the tensile stress of lower surface plate is largest. The stress of core material is so smaller that it’s not obvious in figure (a). In order to make the stress of polyurethane to be more intuitive, figure (b) specially shows stress nephogram of core material. It can be seen from figure (b) that the phenomenon of stress concentration occurs on both sides of the cuboid steel beam in a certain angle, which corresponds with failure locations of specimen shown in Figure.(c) . Since PC1/PC2 made of brittle materials belong to brittle members, compressive property of which is much better than tensile property. Therefore, with the increase of load applied, though compressive stress concentration occurs in the finite element model, there is no phenomenon of compression failure occurring. On the contrary, when the tensile stress of lower surface board which is fiber cement board exceeds the tensile strength, lower surface board occurs brittle fracture failure. Almost at the same time, core polyurethane occurs similar fracture.

The stress nephogram of PCP3/PCP4 which is established with finite element method is shown in figure 6. The meaning of Figure.(a) to Figure.(c) is as same as PCP1/PCP2 mentioned above. It is found from figure (a) that the stress under steel beam is maximum. However, it’s not the main cause of fracture because it’s compressive stress. There is a little difference of fracture path between Figure.(b) and Figure.(c). The potential causes of error between simulation and test are as follows: on the one hand, the material and the interface in finite element model is assumed as homogeneous and ideal respectively. On the other hand, there may be initial imperfection in the specimen, then, the weak part in PCPs may crack during the test.
4.2. Load-deflection curve

Load-deflection curves of FEA and Experiment are shown in Figure.7-Figure.10. FEA represents the results of finite element analysis, and experiment curves are the results of tests. From these results, we can find that the load-deflection curves of banding performance for PCPs are linearly distributed, which means the specimens are in elastic stage before destruction. The potential reasons existing more obviously inaccuracy between two lines of curve in figure 7 may be as follows. Firstly, there is initial imperfection in PCPs. Secondly, it’s impossible to conduct an experiment in ideal conditions, maybe there is a certain friction between high strength steel columns and PCPs. Thirdly, during the test, the stiffness of PCPs is increased because of bearings influenced by artificial factors or external factors which are not ideal hinge bearings. However, the results of simulation coincide well with test in general. It presents important reference significance for the choice of polyurethane PCPs in practical projects.

Figure 6. (a) PCPs stress nephogram (b) Core material stress nephogram (c) Specimen failure

Figure 7. Mid-span load-deflection curve of PCP1. Figure 8. Mid-span load-deflection curve of PCP2.
5. Conclusions
(1) Finite element models for the bending performance of polyurethane composite panel are established. Comparing specimens experiment data with stress nephogram coming from ABAQUS, it’s found that the failure feature of PCPs whose lower structural surface board is fiber cement board presents brittle fracture under vertical load, failure beginning with lower surface board. The failure of PCPs whose lower structural surface board is color steel plate also shows the feature of brittle fracture, but failure beginning with the bottom of core material. Both kinds of failures what have been mentioned above are tension failures. And the specimen failure coincides well with stress cloud.

(2) In view of bending performance of polyurethane composite panels with different thickness and materials of surface board, comparing the simulation results got through finite element method (shown in Figure.11) with the results from experiments (shown in Figure.2), it can be seen that their tendencies are similar. Both the simulation and the experiment results show that the thicker the surface plate of PCPs is, the higher their stiffness and the stronger their bearing capacity become. On the same conditions, the color steel plate could be used to improve the ductility of polyurethane composite board.

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