The Structure and Strength Analysis of an Automated Prefabricated Component Manufacturing Mold

Xiaochen Zhang[1, a], Yijun Wu[1, b] and Yanze Long[2, c*]

[1]School of Mechanical Engineering, Shenyang Jianzhu University，Shenyang, Liaoning, 110168，China

[2]College of Engineering Training and Innovation, Shenyang Jianzhu University，Shenyang, Liaoning, 110168，China

[a]e-mail: xczhang@sjzu.edu.cn,
[b]e-mail: yijunwu@stu.sjzu.edu.cn
*Corresponding author: [c]e-mail: lonyanze@sjzu.edu.cn

Abstract. In light of the current complexity in production steps for prefabricated components within the prefabricated construction industry, as well as the significant proportion of costs attributed to molds and mold release equipment in overall production costs. The design of an automated prefabricated component manufacturing mold has been accomplishing using SOLIDWORKS. The mechanical analysis of the demoulding device in the multiple components of the mold is carried out by ANSYS WORKBENCH. The analysis shows that the maximum stress in two special working situations is 45.69MPa and 69.84MPa respectively, and the safety factor is as high as 5.1 and 3.4. Based on the topology optimization technology, the structure optimization design of the demoulding device is carried out to make its structure design more reasonable. After six times of optimization, the safety factor of the demoulding device was reduced to 2.5 and 2.1, which successfully saves 9.2% of the steel quantity and achieves higher production efficiency and performance.

Keywords: Prefabricated Component Manufacturing Mold, Static Analysis, Structural Optimization

1 Introduction

With the rapid development of the prefabricated construction industry, the demand for prefabricated components is increasing. However, the high cost of component production has become an obstacle to the further development of prefabricated construction [1]. At present, 85% of the cost of prefabricated construction is the production cost of prefabricated components, of which labor costs and mold costs account for more than half [2]. The main reason is that the production process requires workers to remove and assemble molds, and the production of prefabricated components of each size requires re-customized molds [3]. Therefore, the realization of automated production can save

© The Author(s) 2024
Q. Gao et al. (eds.), *Proceedings of the 2024 7th International Conference on Structural Engineering and Industrial Architecture (ICSEIA 2024)*, Atlantis Highlights in Engineering 30,
https://doi.org/10.2991/978-94-6463-429-7_21

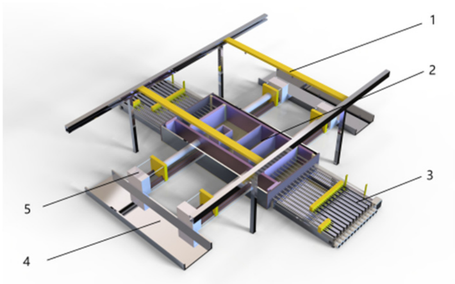
labor costs and the cost of replacing molds, which is conducive to the sustainable development of prefabricated construction.

According to the production requirements of prefabricated components [4]. In this paper, an automatic prefabricated component manufacturing mold is proposed, which can automatically produce prefabricated components and automatically demould. It can produce various sizes of components with only one mold, and does not need manual participation, so that the production cost can be reduced. It is conducive to the development of prefabricated construction.

SOLIDWORKS performed 3D modelling of the mold, and the mechanical properties of the demoulding device, which is the main structure of the mold, were analyzed by ANSYS WORKBENCH, with the actual usage of the mold, the feasibility and rationality of the structure design were proved.

1.1 The Structure of the Mold

The automatic prefabricated component manufacturing mold is composed of demoulding device, size adjustment system, door and window placement system, door and window selection area, and power system, as shown in Figure 1. The center is the placing area where the concrete is put, the left and right sides are the height adjusting mechanism composed of specially shaped sliders, the front and back sides are the length adjusting mechanism with long baffles as the main body, the demoulding device is arranged under the placing area, and the door and window placing system is arranged above the placing area.



1. Door and window placing system, 2. Placing area, 3. Length adjusting mechanism, 4. Door and window selection area, 5. Height adjusting mechanism

Fig. 1. Structure of the automatic prefabricated component manufacturing mold

1.2 The Working Principle of the Mold

Each part of the automatic prefabricated component manufacturing mold is controlled by the central processor to realize the adjustment of the size of the placement area according to the requirements of the drawings. In this way, prefabricated components of various sizes can be manufactured according to requirements, and automatic production can be realized. So that the cycle utilization rate of the mold can be improved and the depreciation rate can be reduced. After the size adjustment is completed, the concrete is placed in the target placement area by the concrete placing machine, and the mold is released by the demoulding device after the prefabricated component is formed. The working process of the demoulding device is shown in Figure 2.

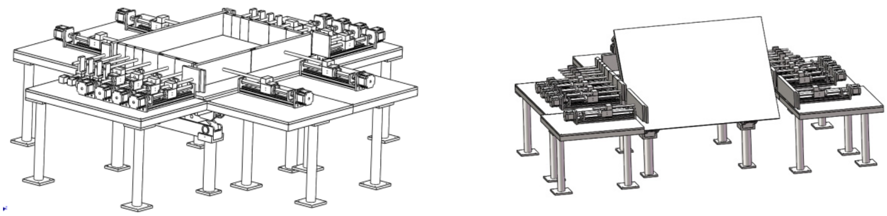
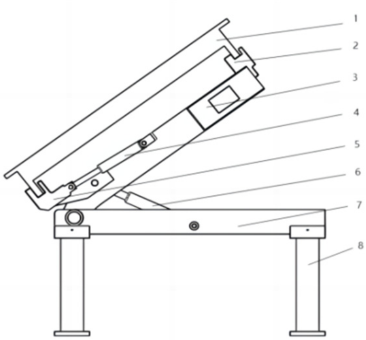


Fig. 2. The working process of the demoulding device

1.3 The Structure of the Demoulding Device

The demoulding device is composed of a placing platform, a tipping mechanism and four pillars. The placing platform is fixedly connected with the upper bracket and the lower bracket. The upper bracket is welded in the square tube at the end of the tipping arm. The lower support is placed on the tilt arm, one end of which is connected with the upper hydraulic cylinder through bolts, and the other end of the upper hydraulic cylinder is connected with the tilt arm through bolts. The front end of the tilt arm is hinged with the base, and the lower hydraulic cylinder is connected with the tilt arm and the base by bolts, respectively. The bottom frame and the column are fixed and connected by bolts. This is shown in Figure 3.

The overall size of the placing platform is 4m×6m×0.5m (L×W×H), and it is made of steel plate with thickness of 20mm and material of Q235B. The material used for the tipping mechanism is Q235B, and the thickness of 15mm steel plate and square pipe are welded. The overall size of the unilateral tipping mechanism is 3.1m×0.3m×0.9m (L×W×H). The pillar is made of 219mm×10mm Q235B pipe, its height is 0.7m. The pillars increase the overall bearing capacity and make the whole frame inverted mold more stable.



1. Placing platform; 2. Upper bracket; 3. Tipping arm; 4. Upper hydraulic cylinder; 5. Lower bracket; 6. Lower hydraulic cylinder; 7. Base; 8. Pillar

Fig. 3. The structure of demoulding device

2 Method

The present study employs the finite element method (FEM) and topology optimization technique. Static analysis is conducted on the demoulding device's structure to verify its sufficient load-bearing capacity for functional realization. Furthermore, based on topological optimization technology, the structural optimization design of the demoulding device is performed to enhance its rationality while reducing material consumption without compromising usage requirements.

2.1 The Establishment of the Finite Element Model

According to the analysis of the normal use process of the demoulding device, two special working conditions are selected to analyze the force of the demoulding device. The first is the process of manufacturing prefabricated components, including the horizontal position before demould, that is, the state of 0° relative to the horizontal plane of the tipping mechanism, as shown in Figure 4. The second is the process of demould, that is, the state of 30° relative to the horizontal plane of the tipping mechanism, as shown in Figure 5.

The models of the two special working conditions were converted into .x_t format and imported into ANSYS WORKBENCH, respectively, to establish the finite element model [5]. The mechanical properties of simulated materials were an important input data to the computational simulations. Material properties such as young's modulus and Poisson's ratio can be utilized by computer generated analysis to describe the mechanical behaviors, induced stresses, or the relationship between forces and displacements for a structural element [6,7]. According to the material used by the demoulding device, set its material properties in WORKBENCH. The material of the inverted mold device is Q235B. According to the material manual, the density of this material is 7.25g /cm³, the yield strength is 235 MPa, the elastic modulus is 206GPa, and the Poisson's ratio is 0.3 [8].

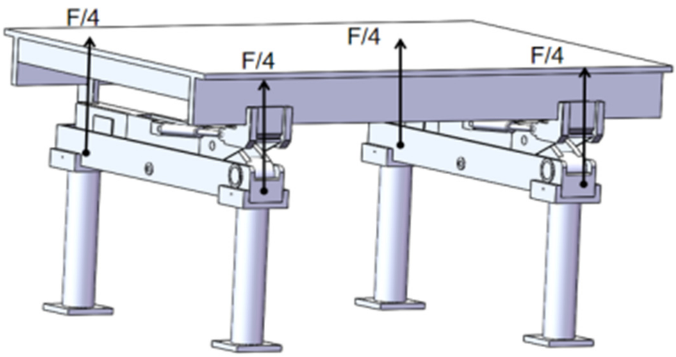


Fig. 4. The first special condition

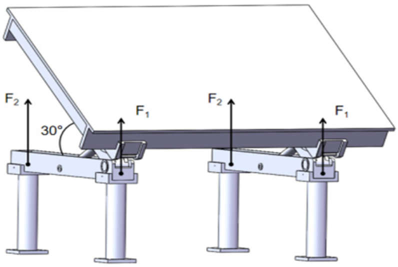


Fig. 5. The second special condition

2.2 Meshing

Meshing was performed using Aggressive mechanical in ANSYS WORKBENCH. Due to the large size and simple structure of the demoulding device, the mesh size was selected to be 20mm, and then the meshing result of the entire model was obtained. The inverting device is divided into 1169690 cells and 644615 nodes, the results are shown in Figure 6.

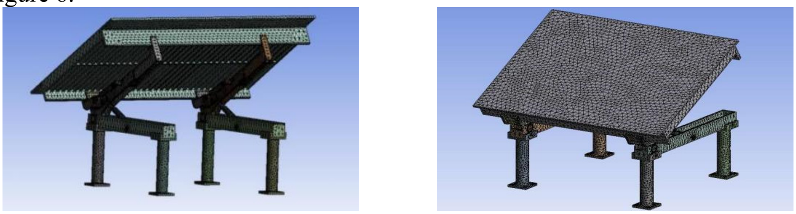


Fig. 6. Meshing result of the demoulding device

2.3 Loads and Boundary Condition

In addition to its gravity load, the main force borne by the demoulding device comes from the gravity load of the prefabricated component and the placing platform. Therefore, a vertical downward force equal to the gravity load of the prefabricated component is directly applied to the surface of the placing platform in direct contact with the prefabricated component. According to the actual use scenario, fixed constraints are imposed on the bottom of the four pillars of the demoulding device. The loads of the demoulding device and prefabricated component are shown in Table 1.

Table 1. The loads of the demoulding device and prefabricated component

category	Load [N]
placing platform	34800.0
Tipping mechanism	16620.0
Pillar	471.2
prefabricated component	225000.0

3 Results and Discussion

3.1 The Finite Element Results

The finite element analysis results of the demoulding device as a whole are shown in Figures 7 and 8. The stress in most positions of the overall structure of the demoulding device is relatively small, and only the stress in some positions is relatively large and concentrated.

According to the analysis results in Figure 7, in the first special working condition, the maximum stress occurs at the end of the tipping arms of the tipping mechanism, specifically at the contact point between the tipping arms and the support structure of the placing platform, and the maximum stress is 45.69MPa. According to the analysis results in Figure 8, in the second special working condition, the maximum stress occurs at the lower bracket of the tipping mechanism, specifically at the contact point between the lower bracket and the lower support structure of the placing platform, and the maximum stress is 69.84MPa. According to the calculation formula of the safety factor of the mechanical structure, the yield strength of the material used is 235MPa, and the safety factor under the first working condition is 5.1, and the safety factor under the second working condition is 3.4, both of which meet the strength conditions.

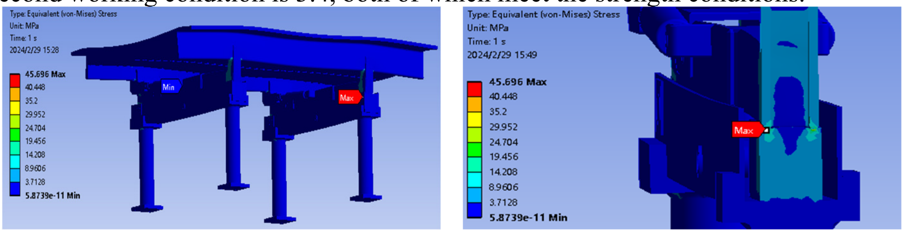


Fig. 7. The equivalent stress distribution cloud diagram of the first special condition

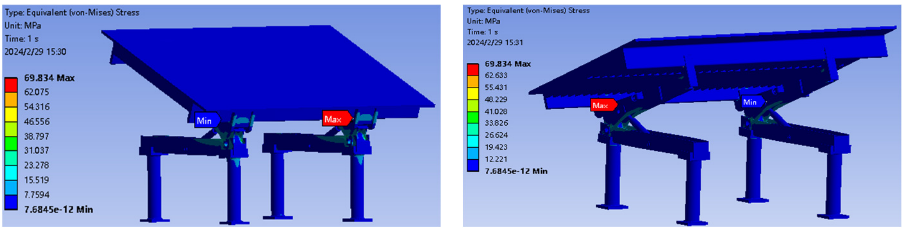


Fig. 8. The equivalent stress distribution cloud diagram of the second special condition

3.2 Topology Optimization Scheme

The safety factor of the whole structure of the demoulding device is too high, which will waste materials and may also affect the flexibility of the structure. Therefore, optimize and improve the overall structure of the demoulding device by the topology optimization technique [9].

The optimization object is the structure size of the overall structure of the inverted die device, and the optimization constraint is that the maximum stress of the overall structure of the demoulding device does not exceed the yield strength of the material. The optimization objective is to reduce the overall quality of the demoulding device.

Using the Shape Optimization module for optimization analysis, the quality reduction target was set to 5% each time in this study, and the least important 5% of the inverted mold device structure was automatically identified by the software. After six topology optimization improvements, it is found that the maximum stress of the overall structure of the demoulding device is close to the yield strength of Q235 material. Figure 9 shows the topology optimization result of the overall structure of the demoulding device, where the dark red area is the unimportant area, and this part of the material can be considered to be cut.

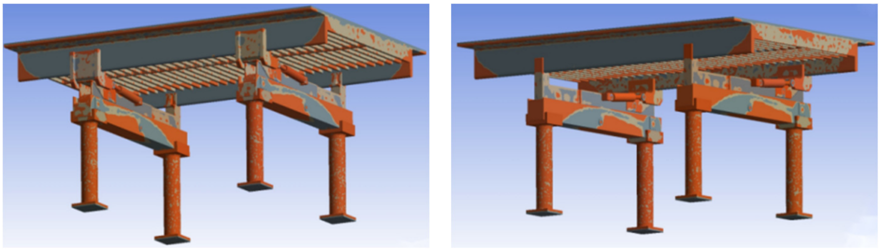
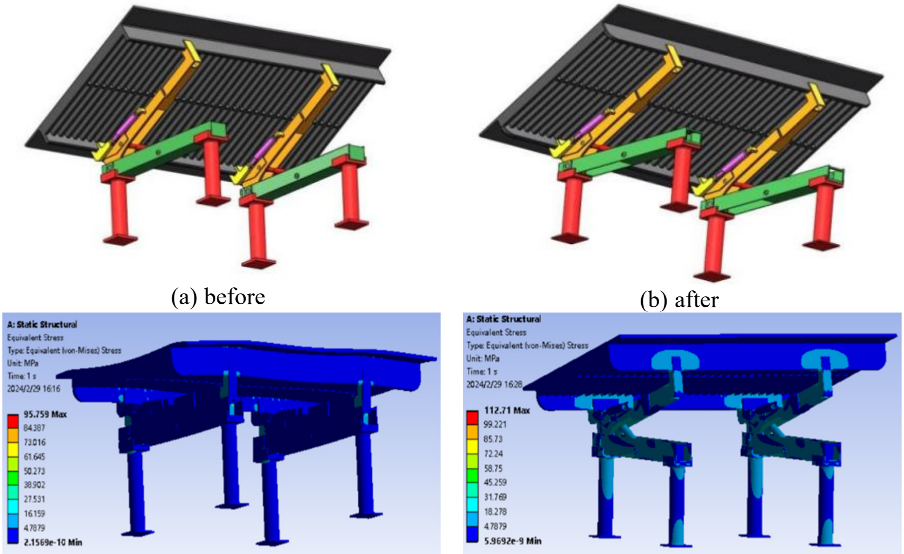


Fig. 9. The topology optimization results of the demoulding device

3.3 Structural Optimization Results

According to the results of topology optimization, after six improvements to the overall structure of the demoulding device, Figure 10 shows the structure diagram of the demoulding device before and after optimization. Figure 10 is optimized by cutting or removing the dark red area in Figure 9 on the basis of the original structure. The specific locations are the two sides of the front section and the bottom area in the base, the upper-end area of the pillars and the two ends of the supporting rib plate of the placing platform.

According to the optimized structure size, the static model was established again according to the same procedure to verify the mechanical performance of the overall structure of the optimized demoulding device. Except for the structural differences between this model and the model above, the other model parameters are the same to ensure the comparability of the results. Figure 10 shows the stress distribution cloud diagram of the overall structure of the demoulding device after optimization. The stress distribution also shows the characteristics of non-uniform distribution, but the maximum stress under two special working conditions is 95.74MPa and 112.71MPa, respectively, which are higher than those before optimization. According to the safety factor calculation formula, the overall structural safety factor of the optimized inverted mold device is 2.5 and 2.1, which reduces the amount of material and ensures the safe and reliable operation of the structure.



(a) before (b) after

(c) The first special condition (d) The second special condition

Fig. 10. The stress nephogram of the before and after optimization

4 Conclusion

In this study, the design of an automated prefabricated component manufacturing mold has been accomplished using SOLIDWORKS. The mechanical analysis of the demoulding device in the primary body mechanism was carried out by using ANSYS WORKBENCH. The statics analysis results show that the maximum stress of the demoulding device under two special working conditions is 45.69MPa and 69.84MPa, respectively, which is far lower than the yield strength of Q235 material, and the safety factor is 5.1 and 3.4. Through topological optimization technology, after 6 times of optimization, the material is reduced and removed from the two sides of the front section and the bottom area in the base, the upper-end area of the pillars and the two ends of the supporting rib plate of the placing platform. The static analysis of the optimized structure is conducted once again, revealing that the optimized safety coefficients are 2.5 and 2.1, which can ensure the regular operation of the structure. After optimizing the overall structure of the system, the amount of steel is reduced by 9.2% compared with that before optimization, and the purpose of lightweight is achieved.

Based on the above data, the feasibility of the demoulding device is verified in this paper, which will provide a reference for the design of automatic prefabricated component equipment and the research of prefabricated component demoulding device.

Acknowledgments

This project is supported by National Natural Science Foundation of China (Grant No. U23A20631), "The open competition mechanism to select the best candidates" Special Project for Science and Technology Tackling Key Problems of Liaoning Province (2022JH1/10400028), Program of Construction Platform for Ultra High and Special-shaped Building of Commission for Education and Technology of the CPC Shenyang Municipal Committee (2024SFW04).

References

1. Zhou, Q., Ma, J.H., Zhang, D.G., et al. (2020) Research on Standardization and Generalization of Steel Mould for PC Component. China Concrete and Cement Products, 82-85.
2. Han, X., Zhu, Y.J. (2024) Analysis of Prefabricated Construction Cost Control. Green Building, 20-24.
3. Wu, L.H. (2024) Research on the development bottleneck and future development trend of prefabricated buildings. Learning, 141-143.
4. Nam, S., Yoon, J., Kim, K., et al. (2020) Optimization of Prefabricated Components in Housing Modular Construction. Industrialized and Automated Construction in the Context of Sustainability, 12: 1-22.
5. Tickoo, S. (2020) ANSYS Workbench 2019 R2: A Tutorial Approach, 3rd Edition. CADCIM Technologies, Nadiad.
6. Moreira, T.M.M., Godefroid, L.B., Faria, G.L.D, et al. (2019) Computational Analysis Via FEM of Tirefond Screws Used in the Fastening System of Railroads Aiming to Avoid a Recurrent Failure Case. Engineering Failure Analysis, 106: 1-12.
7. Kriswanto, Supraptono, et al. (2021) Static Structural Analysis and Determination of Low-Cost Component Sizes of The Paper Pulper Machines. In: The 9th Engineering International Conference. Semarang, Indonesia. pp.1-13.
8. Song, L. (2021) Structure Strength Analysis of ZC10000 Hydraulic Support Base Based on Workbench. Mechanical Management and Development, 36: 90-92.
9. Zhang, k. (2023) Static Analysis and Structural Optimization Design of Coal Mine Seraper Conveyor Head Frame. Automation Application, 64: 195-197.

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