Study on the Forming Process of Prefabricated Reinforced Concrete Thin-Walled Molds in Complex Cavities

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Abstract: This study investigates the pouring process and quality control of PRC thin-walled permanent formworks with complex cavities. Computational Fluid Dynamics (CFD) simulates the pouring process, L-shaped box flowability tests calibrate simulation parameters. Simulations focus on an actual bridge project, analyzing flow characteristics and potential defects. Criteria for pouring PRC thin-walled molds are established, along with auxiliary pouring methods. This study enhances understanding and optimization of PRC formwork, improving pouring uniformity and quality assurance for construction applications.

Keywords: PRC thin-wall molds; concrete forming process, computational fluid dynamics (CFD); L-shaped box test; forming quality prediction.

1 Introduction

The emergence of prefabricated reinforced concrete (PRC) thin-walled permanent molds, utilizing core-shell separation, marks a significant advancement in prefabrication technology. These molds, tailored for high-load components, excel in transportation and lifting. PRC molds serve as formwork for pouring concrete and enhance overall structural load-bearing capacity, gaining attention in civil engineering.

In practical engineering, designing complex cavities in thin-walled structures poses challenges for concrete pouring due to limited flowability and dense reinforcement. To tackle this, the paper utilizes CFD with the Volume of Fluid (VOF) method to simulate Ultra-High Performance Concrete (UHPC) flow. Comparing simulation with L-shaped box tests, it determines H-B model parameters for UHPC flow. Lastly, using a real cantilever cap beam project, the study simulates UHPC pouring into PRC thin-walled molds, examining flow characteristics and predicting quality defects.

2 Experimental procedure

The shape and dimensions of the L-shaped box are illustrated in Figure 1. During the test, the L-shaped box is placed on a level, solid surface, and the movable gate is closed. The inside of the mold is wetted with water and any excess water is wiped away. The vertical section of the apparatus is then filled with a concrete sample. After allowing it to rest for one minute, the movable gate is lifted, and the time it takes for the concrete to flow through the designated points is recorded. During the test, the time for the concrete to reach the furthest point and the flow patterns at different times are recorded. The experiment utilized two types of concrete materials: normal strength concrete (NC) and UHPC.

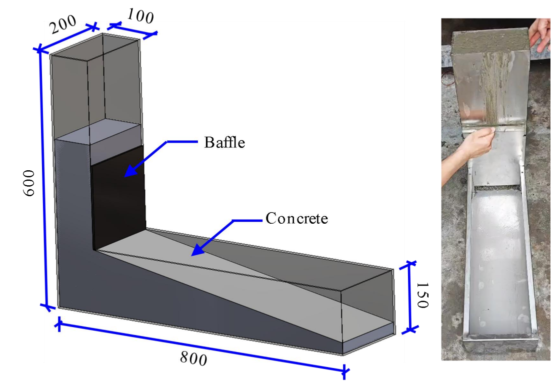

Figure 1 L-shaped box dimensions (unit: mm)

3 Numerical simulation procedure

Research shows UHPC shares shear thickening traits with self-compacting concrete [1, 2]. To simulate this, the Herschel-Bulkley (H-B) rheological model, with yield stress, offers superior accuracy over the Bingham model [3, 4]. Employing a pressure-based, transient, implicit segregated solver, the simulation sets a reference pressure point outside the model at standard atmospheric pressure. Gravity is considered in the y-direction, while thermal exchange is omitted. In the multiphase material, air and concrete are represented, with concrete characterized by the H-B model. Boundary conditions include a pressure inlet with zero relative pressure and a pressure outlet to aid convergence during backflow. Flow equations employ second-order upwind discretization, with pressure-velocity coupling via the SIMPLE algorithm. Momentum equations use first-order upwind discretization, and fluid interface tracking employs the Geo-Reconstruct scheme.

4 Result and discussion

L-shaped box tests

L-shaped box tests were conducted separately for NC and UHPC. The NC could not flow autonomously and required placement on a vibration table to complete the L-box flow test. In contrast, UHPC exhibited excellent flowability, flowing smoothly upon the opening of the movable gate and reaching the marked position (600mm from the gate) within 10.10 seconds. As a result, this study focuses solely on simulating the flow of UHPC, as shown in Figure 2, the number 1 represents air, and the number 0 represents concrete, and any cross-section consists of these two materials. During the test, the time taken for the UHPC to reach the furthest point and the flow patterns at different times were recorded. The results demonstrate that CFD simulation can effectively replicate the pouring process.

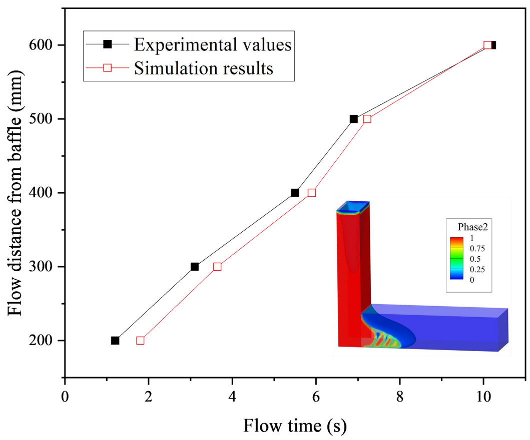

Figure 2 Comparison between UHPC L-shaped box test and simulation

PRC thin-walled molds

The thin-walled cap beam shell utilizes a three-segment prefabricated scheme, as shown in Figure 3(a). Its overall dimensions are 38.2 m in length and 4m in width, with symmetrical sections on both sides. The left and right segments are each 13.7 m in length, while the middle segment is 10.8 m, and the maximum depth is 5.5 m. The thickness of the bottom slab is 0.3 m, and the thickness of the web is 0.28 m.

The CFD model employs simulation parameters consistent with those of the L-shaped box test. The pouring inlet and outlet are illustrated in Figure 3(b), where the blue arrow represents the calculated inlet with a velocity of 0.5 m/s. The top surface, excluding the inlet gate, serves as a pressure outlet indicated by the red arrow, while the remaining surfaces are designated as walls. Due to the structural complexity and to enhance computational efficiency, a tetrahedral unstructured mesh with four nodes is utilized for discretization. The edge sections of the cap beam are partitioned into 490,282 mesh elements, while the central section comprises 498,536 mesh elements.

The computational results are depicted in Figure 3(c). As shown in the figure, the red area represents the completed pouring region, while the blue portion indicates areas where pouring is incomplete, mainly situated above the outlet. These areas can be filled after the pouring process is finished. The yellow and green regions lie between the completed pouring and incomplete areas, indicating zones containing air bubbles. They are predominantly concentrated at the bottom of the model, corners, and the bottom surface farther from the pouring inlet. These areas require auxiliary vibration to ensure pouring quality.

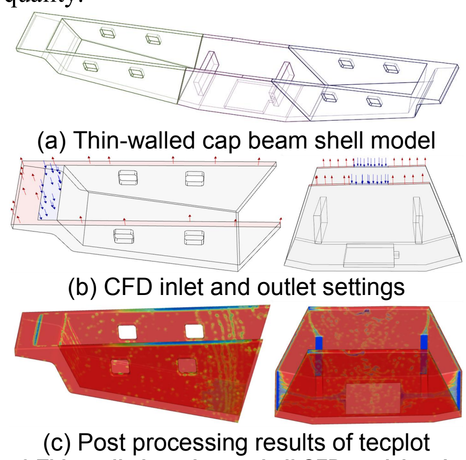

Figure 3 Thin-walled cap beam shell CFD model and results

5 Conclusion

This study utilizes CFD with the H-B rheological model to simulate the flow characteristics of UHPC. By comparing numerical simulation results with experimental data, the reliability of the H-B model in simulating the flow behavior of shear-thickening power-law fluid UHPC within molds is validated. The simulation findings provide guidance for predicting the quality of UHPC pouring in thin-walled structures.

References

[1] Wang X, Ma Z, Wang X, Xue S, Shen W, Wu D, et al. Design of self-compacting ultra-high performance concrete (SCUHPC) towards to the cementitious materials packing optimization. Cement and Concrete Composites. 2024;148:105443.

[2] Yu R, Xu L, Li K, Leng Y, Wang Z. Dynamic behaviors assessment of steel fibres in fresh Ultra-High Performance Concrete (UHPC): Experiments and numerical simulations. Journal of Building Engineering. 2022;59:105084.

[3] He J, Cheng C, Zhu X, Li X. Effect of silica fume on the rheological properties of cement paste with ultra-low water binder ratio. Materials. 2022;15(2):554.

[4] Jirout T, Krupica A, Kolomijec A. CFD analysis of ultra-high-performance concrete rheological tests. Fluids, 2024, 9(2): 45.