Flow Control in a Twin-Shaft Forced Mixer through the Combined Optimization of Blade Shape Continuity, Inclination Angle, and Rotation Direction, and Its Effects on Ultra-High-Performance Concrete Production

AUTHOR

Takeshi KAGOTANI*1

ABSTRACT

This study aims to improve the mixing efficiency and quality uniformity of ultra-high-performance concrete through the combined optimization of blade shape continuity, inclination angle, and rotation direction in a twin-shaft forced mixer. While previous studies have examined these parameters independently, the present research focuses on their interactions and proposes an integrated optimization approach, together with a flow control method for each mixing stage. Experiments were conducted using a visualization mixer and a test mixer with a capacity of 60 L. The inclination angles (0°, 15°, and 35°), rotation directions (forward and reverse), and blade shape continuity were varied. Flow analysis was performed to identify optimal internal flow conditions within the mixer. Mixing tests of mortar were also conducted using high-strength mixtures and demonstrated that switching the rotation direction between the initial and later mixing stages was effective in optimizing both compressive strength and air content. This study provides valuable insights for energy-efficient production and optimized mixing processes for future ultra-high-performance concrete production.

1. Introduction

Twin-shaft forced mixers are widely used to achieve homogenization and stable quality in concrete, and their flow characteristics strongly depend on geometric and kinematic factors such as blade shape, inclination angle, and rotation direction. In particular, in recent years, materials such as ultra-high-performance concrete (UHPC), which exhibit low water-to-binder ratios and high viscosity, have become increasingly prevalent. For such materials, it has been pointed out that conventional mixer structures often fail to provide sufficient dispersion performance. Consequently, blade design must address not only agitation efficiency but also the optimization of particle circulation flow and shear flow distribution. Previous studies [1–3] individually evaluated blade inclination angle, shape continuity, and rotation direction to quantify their effects on mixing efficiency. The present study integrates these results and proposes a comprehensive flow control method based on the combined optimization of blade shape continuity, inclination angle, and rotation direction. In addition, the mixing process is divided into initial and later stages, and a "stage-wise flow optimization model" is developed, in which the rotation direction is controlled according to each mixing stage.

2. Experimental Methods

In this study, blade inclination angle, rotation direction, and blade shape continuity were defined as the three primary variables. The inclination angle was set at three levels (0°, 15°, and 35°). Blade shapes were compared between discontinuous (paddle-type) and continuous (screw-type) blade configurations, and experiments were conducted under both forward (clockwise) and reverse (counterclockwise) rotation.

Flow analysis was performed using a three-dimensional tracer particle method. A visualization mixer with a transparent acrylic resin casing (capacity: 34.5 L) was fabricated. Tracer particles were placed in pseudo-mortar prepared using a polymer material in the mixer. During agitation, the flow behavior inside the mixer was recorded from the top, bottom, and sides using video cameras. The positional coordinates of the tracer particles were measured to evaluate the material flow velocity within the mixer (see Photo 1 and Figure 1).

For practical-scale testing, mixing experiments were conducted using a test mixer with a capacity of 60 L. Mixing times were set to 60, 120, and 180 seconds. The mixture design targeted a compressive strength of 100 N/mm^2 with a water-to-powder ratio (cement + mineral admixture) of 20%. Mortar was mixed at a volume of 40 L per batch. Mortar flow value, 28-day compressive strength (using Ø50 × 100 mm specimens), and air content were evaluated (see Photo 2 and Figures 2, 3, and 4).

*1 Section Manager, Mechanical Design Section 2, Mechanical Design Department, Technology Management Department, Technical Headquarters, NIKKO Co., Ltd., Ph.D. (Engineering)

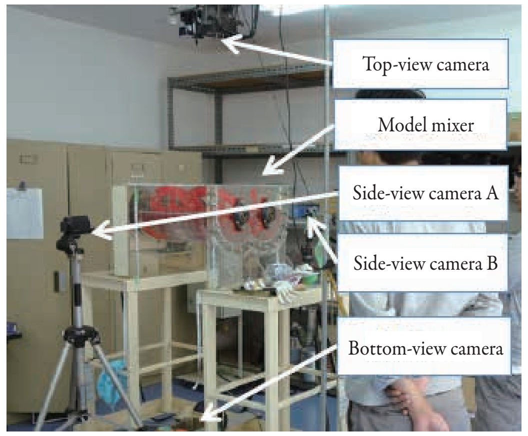


Photo 1: Visualization test setup

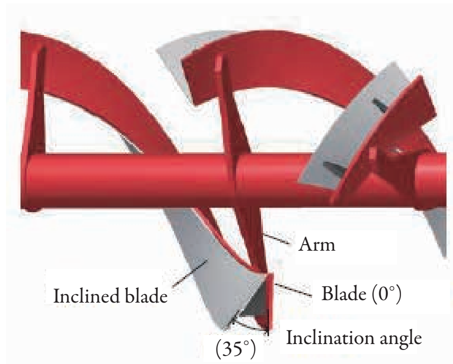
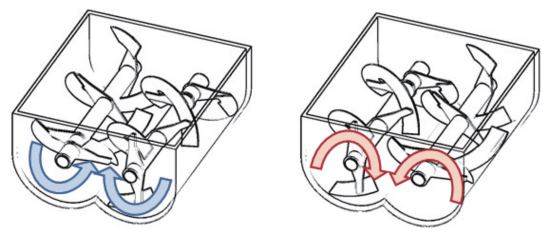


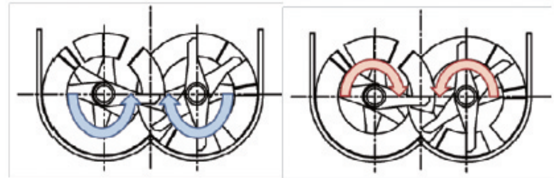
Figure 1: Blade inclination angle



Left: Forward rotation Right: Reverse rotation

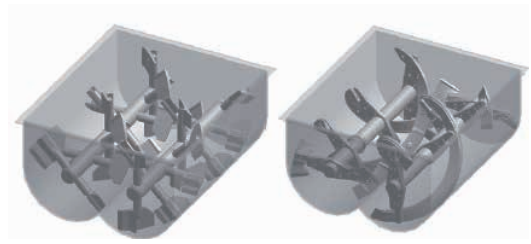
Figure 2: Rotation direction and blade configuration

Photo 2: Test mixer used in this test



Forward rotation Reverse rotation

Figure 3: Blade rotation direction



Discontinuous blade Continuous blade

Figure 4: Conceptual diagram of blade continuity

3. Results and Discussion

As shown in Figure 5, the average flow velocity increased with increasing blade inclination angle. In particular, the vertical velocity component was enhanced, making the vertical circulation flow dominant. This behavior is attributed to the formation of shear layers along the blade surfaces, which balances the floating and settling of coarse aggregates. However, it was observed that when the inclination angle became excessively large, unidirectional flow developed and stagnation occurred near the side walls. Therefore, an inclination angle of around 15° is estimated to fall within the optimal range, avoiding both insufficient and excessive inclination.

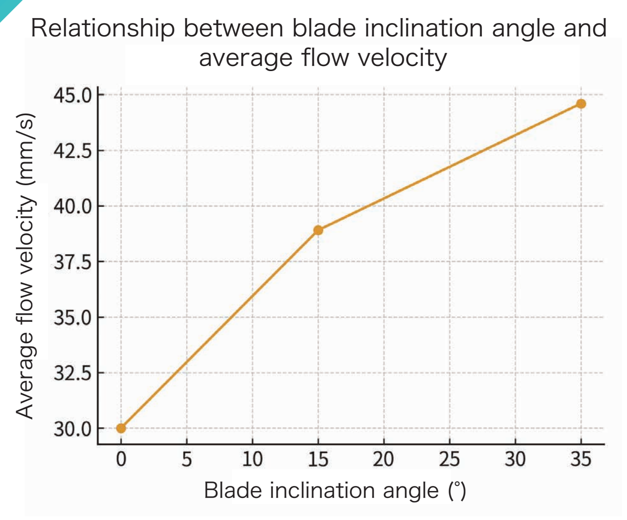


Figure 5: Relationship between blade inclination angle and average flow velocity

Figure 6 shows that when continuous blades were used, the flow value after 60 seconds of mixing was approximately 15% higher than that obtained with the conventional blade configuration. This result is attributed to localized intersecting flows generated by the continuous blades, which homogenize the shear stress distribution and promote early dispersion of particle clusters. In addition, reverse rotation enhanced material dispersion during the initial stage, resulting in rapid homogenization.

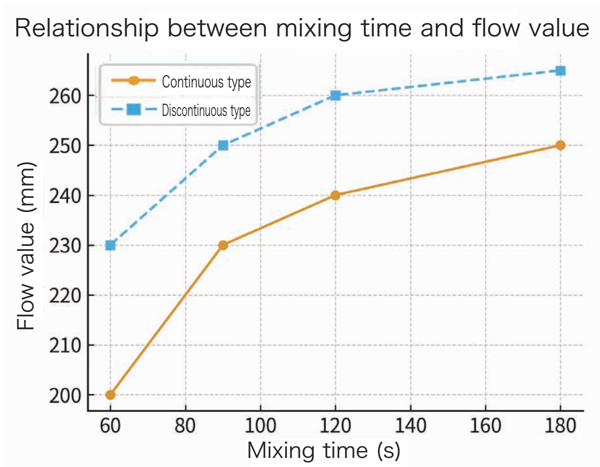


Figure 6: Relationship between mixing time and flow value

As shown in Figure 7, reverse rotation generated high shear energy during the initial mixing stage, promoting particle rearrangement and resulting in high compressive strength within a short time. However, prolonged reverse rotation caused excessive air entrainment, leading to a reduction in strength (see the air content results in Figure 8). In contrast, forward rotation stabilized the flow and maintained high mixture quality during the later stage. These results indicate that a stage-wise control in which reverse rotation in the initial stage is switched to forward rotation in the later stage is the most efficient mixing approach.

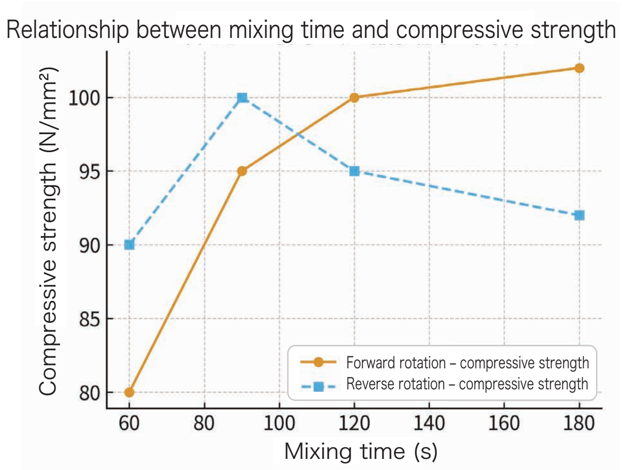
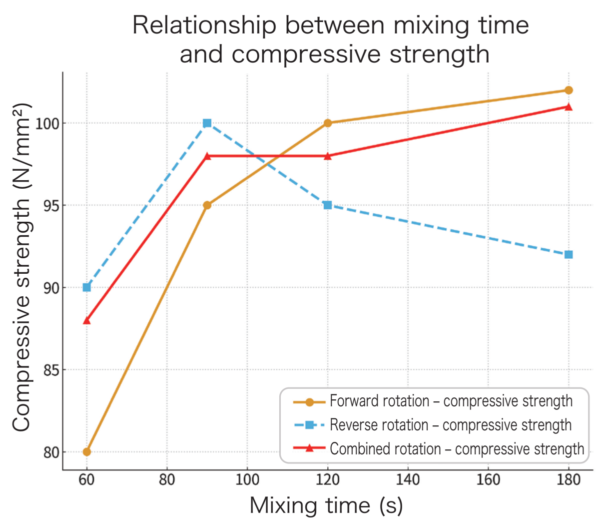


Figure 7: Relationship between mixing time and compressive strength

Figure 8 shows a test conducted with a combined rotation mode consisting of 90 seconds of reverse rotation followed by 90 seconds of forward rotation. This mode was confirmed to simultaneously achieve high compressive strength and low air content. In this mode, a cycle is repeated in which particle clusters are broken up during reverse rotation and rearranged during forward rotation, thereby promoting the homogenization of the flow state. These findings demonstrate that the stage-wise control model achieves both higher efficiency and higher quality than single-direction operation.



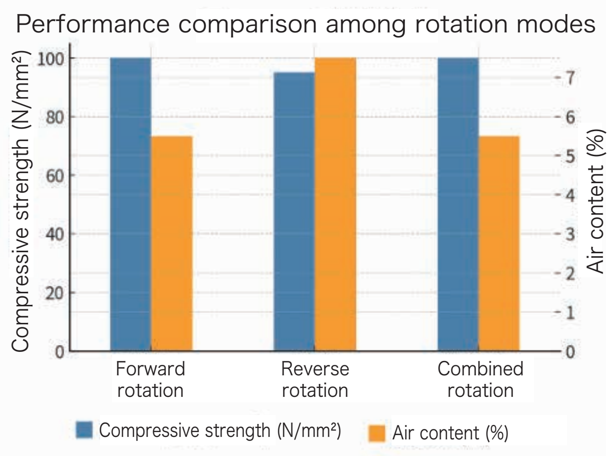


Figure 8: Performance comparison among rotation modes

4. Conclusions

This study proposed a method for simultaneously improving mixing efficiency and quality through the combined optimization of blade shape continuity, inclination angle, and rotation direction in a twin-shaft forced mixer. The findings can be summarized as follows:

1. An inclination angle of approximately 15° provided the highest flow efficiency without causing material stagnation within the mixer.
2. Continuous blades enabled uniform mixing within a short time.
3. Stage-wise control combining reverse rotation in the initial stage and forward rotation in the later stage exhibited the highest overall performance.

These results are significant for future large-scale mixer design and energy-saving efforts, and may serve as practical design guidelines for mixer systems based on flow control principles.

REFERENCES

[1] Kagotani, T., Tamura, T., et al. (2020). Flow analysis and quantification of a twin-shaft forced mixer using a three-dimensional image analysis method.

[2] Yoshida, K., Kagotani, T., et al. (2020). Effect of blade shape in a twin-shaft forced mixer on reducing the mixing time for ultra-high-performance concrete.

[3] Kagotani, T., & Tamura, T. (2021). Effect of mixer rotation direction on the mixing of high-strength concrete.

AUTHOR

Takeshi KAGOTANI

Joined in 2004

Ph.D. (Engineering)
Mechanical Design Section 2,
Mechanical Design Department

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