FUNDAMENTAL STUDY ON MIXING MECHANISM OF CONCRETE IN A CONTINUOUS MIXER BY VISUALIZATION TECHNIQUE

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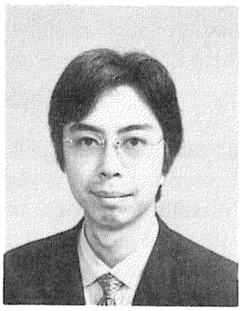
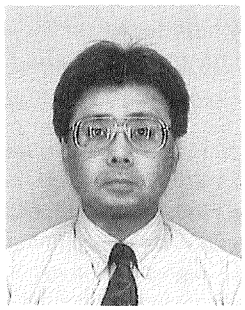
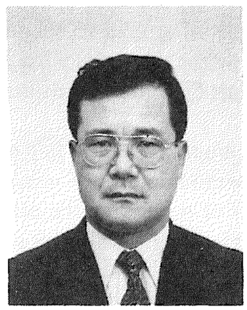

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Mixer angle, blade arrangement and blade shape are crucial to the design of a high-performance continuous mixer. In this paper, the mixing mechanism at work in a continuous mixer was investigated experimentally using a visualization technique.
The blade arrangement and shape of blade are found to be more important to improved mixing efficiency without loss of discharge efficiency than mixer angle.

Keywords: *continuous mixer, visualization technique, mixing mechanism, concrete model, type of blade, mixer angle*

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1. INTRODUCTION

The continuous mixer differs from the batch mixer in the way materials are weighed, and in that materials are continually supplied batched by volume while high-speed mixing is in progress. One problem with this type of mixer was the device used to provide a stable supply of materials, but that has been solved with remarkable advances in machine and facility technology, and a continuous mixer with superior batching precision has now been developed. As a result, the JSCE recommendation "Recommended Practice for Field Mixed Concrete by Continuous Mixer" was published in Japan in 1986. Continuous mixers are easily installed at construction sites, are supplied with materials continually, and offer short mixing times of around 15 seconds. They have found use for special concretes such as shotcrete for NATM or ultra-rapid-hardening concrete for emergency road repairs where limited time is available from the start of mixing to casting.

Generally, the mixer blades in a continuous mixer (the auger) are fixed and can not be replaced. Therefore, in order to improve the mixing performance of continuous mixers, whose mixing time is very short, the method of increasing the mixer angle has been developed to delay mixing time by the action of gravity. With rising demand for site-mixed concrete as construction diversifies and the amount of repair work increases, there is a need to design a high-performance continuous mixer with greater mixing efficiency and adequate discharge efficiency. However, the high-performance continuous mixer can not be designed without grasp of mixing mechanism.

The mixing efficiency of a continuous mixer is evaluated by variability of constituents in fleshly mixed concrete, variability in air content, variability in slump, and variability in compressive strength based on the JSCE Standard "Method of Test for Mixing Efficiency of Continuous Mixers (JSCE-I 502)"[1]. In the vase of batch mixers, there are studies[2] of the mixing mechanism that allow a quantitative understanding using indirect indexes such as the power consumption. However, such indexes do not apply to continuous mixers supplied with materials continually. Furthermore, because multiple types of mixer blades are fitted along the axis of rotation, the flow conditions of the fresh concrete are very complicated, and the mixing mechanism can not be grasped directly.

In this paper, in order to establish a method of evaluating the mixing mechanism in continuous mixers, we use a newly developed visualization technique for fresh concrete[3]-[5]. Laboratory experiments were conducted to investigate the effects of blade arrangement, paddle blade shape, and mixer angle on the behavior of the concrete. In addition, an evaluation of mixing performance by washing analysis was conducted.

2. SUMMARY OF EXPERIMENTS

2.1 Model Continuous Mixer

An outline of the visualization arrangement with a model continuous mixer is given in Fig.1. The auger section, from the materials inlet to the outlet, was model to 1/3 scale, and the speed of revolution and mixer angle can be changed at will. In order to view the auger from below, and to prevent mixer stalling and damage by coarse aggregate, a 2mm transparent vinyl sheet was used as the semicircular bottom enclosure.
The various types of steel mixer blade are shown in Fig.2; these can be installed along the axis of rotation in any order. The screw blade drives materials along the mixer axis, and the two types of mixing blades are paddle designs with two or four blades that shear materials at a dip angle of 30 degrees such as an actual machine.

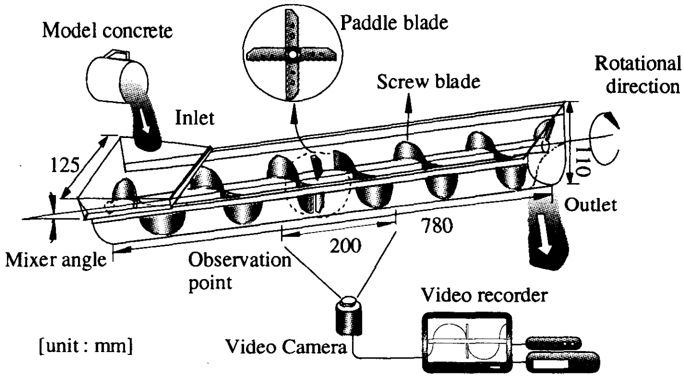


Fig.1 Illustration of model continuous mixer

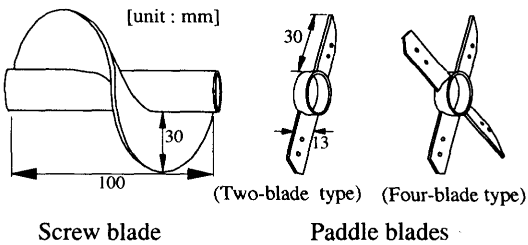


Fig. 2 Types of blades used in continuous mixer

2.2 Model Fresh Concrete

The fresh concrete was assumed to be a solid-liquid two-phase mixture of mortar and coarse aggregate. On this basis, a model concrete was developed. It consists of a mixture of high-polymer resin solution (of specific gravity 1.0) as the model mortar and glass beads (of particle size 12.5mm and specific gravity 2.5) as the model coarse aggregate. Hashimoto et al.[3] used coarse artificial lightweight aggregates as model coarse aggregates. However, mixing stalled as a result of artificial lightweight aggregate catching in the gap between blade and enclosure. Thus, glass beads of a single particle size were selected for this experiment to prevent such problems. The difference in specific gravity as 1.5 between glass beads and model mortar is larger than the difference in specific gravity as 0.4 between coarse aggregate and mortar of actual concrete. Therefore, in order to secure suitable resistance to segregation, the consistency of the model mortar was increased (P-type funnel time around 200 seconds according to the JSCE Standard "Test Method for Fluidity of Grout Mortar for Preplaced Aggregate Concrete (JSCE-F 521)").

To match the mix proportion actually used in continuous mixers[6], the volumetric ratio of model mortar to model coarse aggregate was 0.8. In order to trace the behavior of the model concrete, a tracer consisting of styrene foam particles (of particle size about 2mm and specific gravity 0.02) were added to the model concrete.

2.3 Experimental Method

Three main factors were considered in the mixing mechanism experiments on model concrete using this visualization equipment: the blade arrangement, the paddle blade shape, and the mixer angle. The blade arrangements are illustrated in Fig.3: (a) screw blade only, (b) one paddle blade, and (c) two paddle

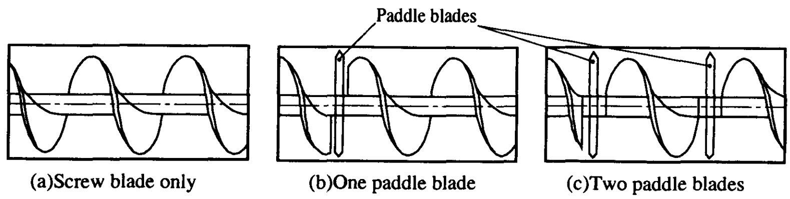


Fig.3 Arrangements of blades at observation point

blades at the observation point. The paddle blades for providing shear have already been illustrated in Fig.2; two-blade type and four-blade designs are tested. Experiments with different paddle blade shape were conducted using case (c) in Fig.3. Screw blades were used at points away from the observation point. The mixer angle was set at 10, 15, and 20 degrees. Mixing speed was 60 rpm after consideration of the size of the model and the passage time of the model concrete through the mixer (actual machine around 160-250 rpm).

While model concrete was added, flow behavior at the observation point was recorded using a video recorder (8mm video camera and others). The amount of model concrete added was that needed to keep the inlet full. The observation point was a central area 200mm long on the underside of the model mixer, where the effects of flow disorder due to material addition or discharge were a minimum (see Fig.1). To analyze the resulting images, the distance moved by the tracers per unit time in the video images was used to obtain the distributions of velocity vectors mapped onto a two-dimensional plane. The time interval for tracer measurements was 0.25 seconds, and more than 200 velocity vector were measured in each experiment.

3. RELATIONSHIP BETWEEN PERFORMANCE OF CONTINUOUS MIXER AND VELOCITY VECTORS

As indexes with which to quantitatively evaluate the flow mechanism in the model continuous mixer on the basis of the velocity vector distributions, the direction of the velocity vector and its size are defined as follows (see Fig.4).

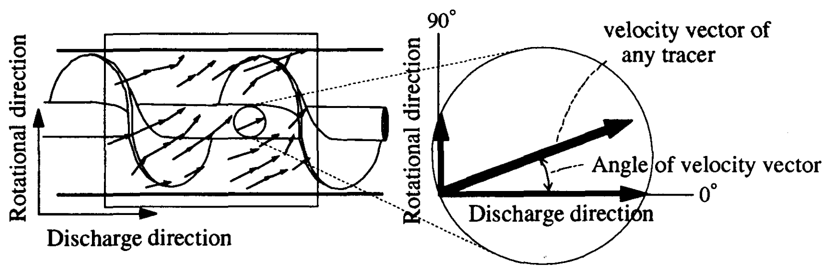


Fig.4 Angle and components of velocity vector

1) Direction of the velocity vector :
The discharge direction is treated as 0 degrees, and anti-clockwise is treated as the positive direction. Individual velocity vectors in arbitrary directions were discriminated every 15 degrees, and the appearance ratio, or the number of occurrences in each 15-degree range divided by the total number of velocity

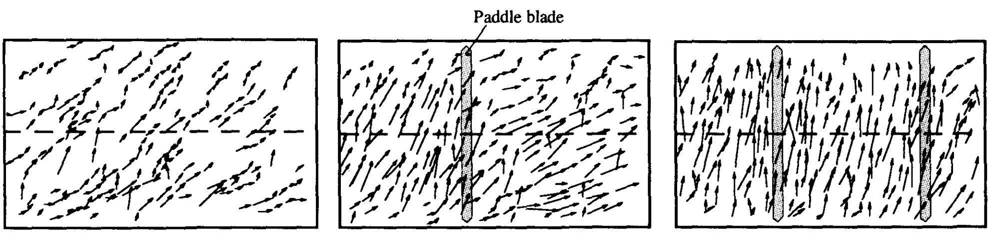
vectors, was computed. The appearance ratio is expected to evenly distributed when mixing performance is high.

2) Size of the velocity vector :
Individual velocity vectors were divided into discharge direction component and a rotational direction component, with each component discriminated every 10mm/s, and a ratio was computed in the same way as for velocity vector direction. The discharge direction component of velocity indicates retention time in the mixer and is related to the discharge efficiency (m^3/h) of the concrete; it is expected that discharge efficiency will be greater when the discharge direction component is larger. The component in the rotational direction is related to the shear flow induced by the mixer blades, and in order to improve mixing efficiency it is important to increase this component, and make sure it does not converge in one particular direction but is dispersed evenly.

4. EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Influence of Blade Arrangement

Figure 5 shows the velocity vector distributions of tracers in the model concrete at a mixer angle of 15 degrees for three blade arrangements shown in Fig.3. The actual location of the paddle blade is shown in each figure. In the case of the screw blade only, it is recognized that a uniformly angled flow occurs and the concrete heads in the discharge direction continually. With one paddle blade in place, the flow moves in the rotational direction immediately before the paddle blade. As the flow passes through the paddle blade, the degree of freedom of the flow increases suddenly, bringing about larger velocity vectors than in the case of the screw blade only. In the case with two paddle blades, the flow direction converges significantly in the rotational direction.



(a)Screw blade only (b)One paddle blade (c)Two paddle blades

Fig.5 Velocity vector distribution of tracer by blade arrangement

The distribution of velocity vector direction is shown in Fig.6. In the case of screw blade only, the ranges 30 to 45 degrees and 45 to 60 degrees occur most frequently. With one paddle blade, there are fewer vectors in the range 30 to 60 degrees, and more in the range 60 to 75 degrees. In the case with two paddle blades, the distribution moves toward 90 degrees, and peak value is in the range 75 to 90 degrees. The average appearance ratio is also higher in the latter case. By increasing the number of paddle blades, it is recognized that the flow in the discharge direction, as imposed by the screw blade, decreases. Furthermore, the rotational direction flow becames more pronounced. This tendency is recognized

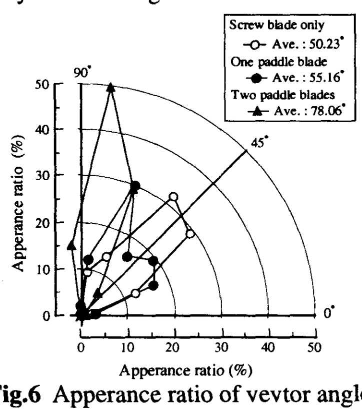


Fig.6 Apperance ratio of vevtor angle by blade arrangement

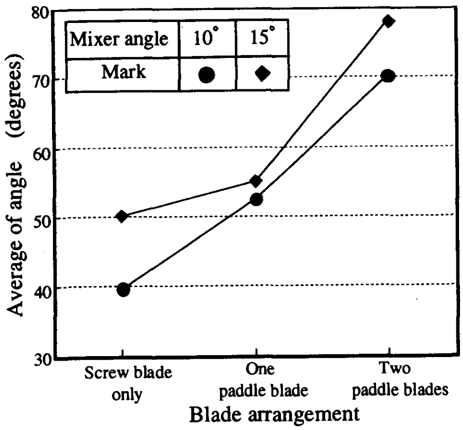
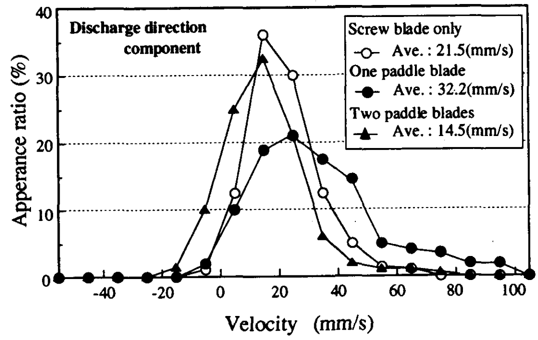
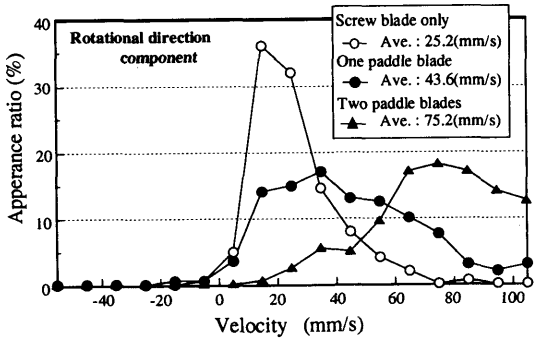


Fig.7 Average angle by blade arrangement



(Discharge direction component)



(Rotational direction component)

Fig.8 Velocity distribution of each component by blade arrangement

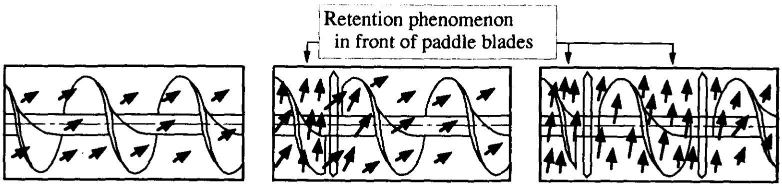
whatever the angle of the mixer (see Fig.7).

Figure 8 shows the appearance ratio of the discharge direction component and the rotational direction component of velocity vector. The discharge direction component generally tends to converge on a peak of 10-20mm/s. In comparison with the case of the screw blade only, the peak value become smaller and the average appearance ratio decreases in the case of two paddle blades. This tendency indicates a decrease in discharge efficiency because of a lower concrete flux in the discharge direction. However, the average of the appearance ratio in the case of one paddle blade is larger than in the case of screw blade only, so it is concluded that the discharge efficiency is rather better. This can be explained by the higher velocity arising at the point where the concrete passes through the paddle blade, as noted in Fig.5. The appearance ratio of the rotational direction component converges on one fixed velocity in the case of the screw blade only. By increasing the number of paddle blades, the distribution of velocities improves, the appearance ratio of 40mm/s or more increases, and the average of the appearance ratio is also higher. It seems that flow in the rotational direction is activated by the paddle blades.

As stated above, flow in various directions and velocities arises with the paddle blade in comparison with the case of screw blade only. As a result, it is concluded that mixing is more active. When the number of paddle blades increases, the discharge efficiency decreases. Considering that the paddle blade rotates at high speed and the concrete is being mixed, it is estimated that this can be attributed not to the formation of shear flow by the paddle blades, but by partial retention in the front of the paddle blade where the flow area in the discharge direction decreases (see Fig.9).

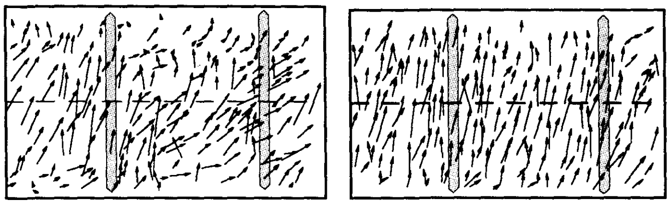
4.2 Influence of Shape of Paddle Blade

Figure 10 shows the velocity vector distributions for the two types of blade - the two- and four-blade paddles (see Fig.2) at the two points of arrangement (c) shown in Fig.3. For both designs, the flow became more rotational. The degree to which this happens is less with the two-blade type with the in



(a)Screw blade only (b)One paddle blade (c)Two paddle blades

Fig.9 Notion of patial retention phenomenon by paddle blades



Two paddle blades with two blades each Two paddle blades with four blades each

Fig.10 Velocity vector distribution of tracer by shape of paddle blades

four-blade type, and angled flow occurs between the paddle blades with the two-blade type. It is thought that this can be attributed to the larger flowable area of the two-blade type at the paddle blade section.

The appearance ratio of velocity vector direction is shown in Fig.11. In the case of the two-blade type, there is no convergence in one direction. On the other hand, with four-blade type, there is a notable convergence in the rotational direction near 90 degrees.

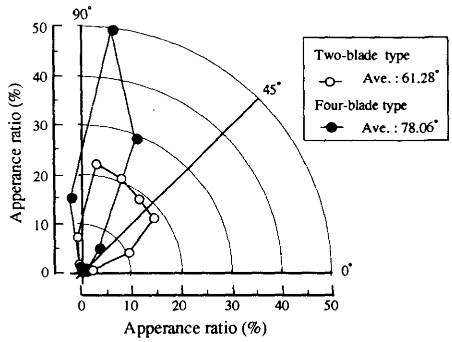
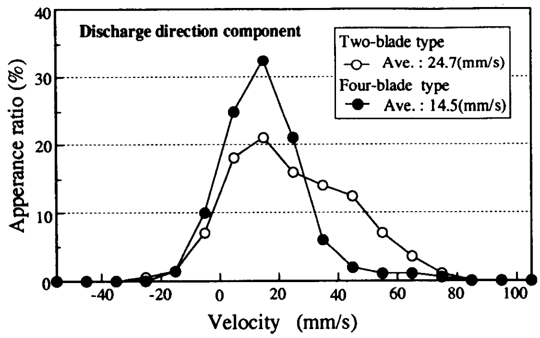


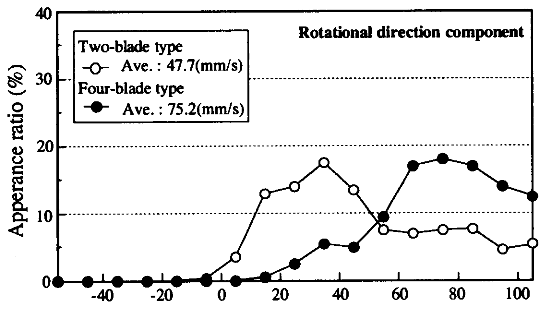
Fig.11 Apperance ratio of vevtor angle by shape of paddle blade

Figure 12 shows the appearance ratio of the discharge direction component and the rotational direction component of the velocity vector. With the two-blade type, there is a wider distribution of velocity, the appearance ratio of velocity vectors of 30mm/s or more is higher, and the average appearance ratio is larger than with the four-blade type. Furthermore, the average with the two-blade type is the same as the average of the discharge direction component when only a screw blade is used, as shown in Fig.8, so discharge efficiency is not compromised. The appearance ratio of the rotational direction component has the same distribution for both types of paddle blade. However, the size of the velocity vector with the four-blade type is greater than with two-blade type, so it is estimated that mixing is more active. Therefore, for a given number of paddle blades, changing from a two-blade design to a four-blade design can be expected to reduce the discharge efficiency and improve the mixing efficiency.

In order to grasp the area affected by the paddle-blade, the velocity vector of divided area near the paddle-blade is evaluated. With two-blade type or four-blade paddle blades at two points in arrangement(b) shown in Fig.3, the axial length centering on the paddle blade is divided into four sections each 40mm long, as shown in Fig.13. Figure 14 shows the average of the discharge direction component and the rotational direction component of the velocity vector in each section. Both direction components have a fixed velocity in the case of the screw blade only. The discharge direction component decreases most in velocity at section(2) for both paddle blade designs, and increases beyond that section. The change is



(Discharge direction component)



(Rotational direction component)

Fig.12 Velocity distribution of each component by shape of paddle blade

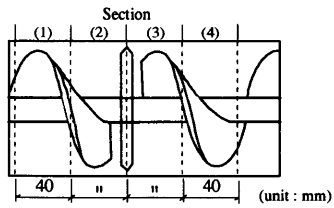
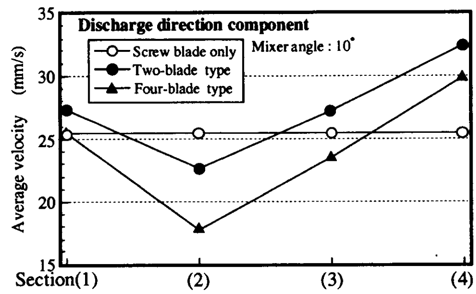
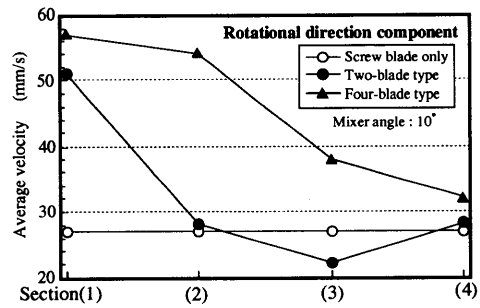


Fig.13 Four areas



(Discharge direction component)



(Rotational direction component)

Fig.14 Average velocity of each section by shape of paddle blade

more pronounced with the four-blade type than with the two-blade type in section(2). On the other hand, in the rotational direction component, the velocity change from section(1) to section(2) is more pronounced with the four-blade type than with the two-blade type. It is recognized that, although there is some direct influence by the paddle blade, the cause of this can be attributed to the partial retention phenomenon at the front of the paddle blade, where the flow area in the discharge direction is restricted. The velocity in sections(3) and (4) to the rear of the paddle blade is different from that of screw blade only, so it is concluded that the effect of the partial retention phenomenon continuesthrough to this area.

4.3 Influence of Mixer Angle

Figure 15 shows the appearance ratio of the velocity vector in case of blade arrangement (b) in Fig.3 for three mixer angle: 10, 15, and 20 degrees. With rising mixer angle, the peak of the velocity vector direction moves from the discharge direction to the rotational direction. The appearance ratio shows the same dispersion whatever the mixer angle.

Figure 16 shows the appearance ratio of the discharge direction component and the rotational direction component of the velocity vector. The appearance ratio of the discharge direction component tends to converge on 0-20mm/s as a peak for any mixer angle, and its average decreases as the mixer angle is

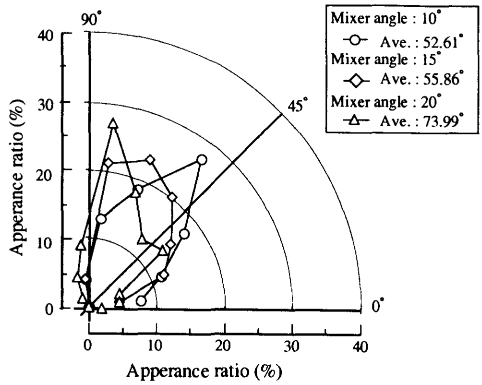


Fig.15 Apperance ratio of vevtor angle by mixer angle

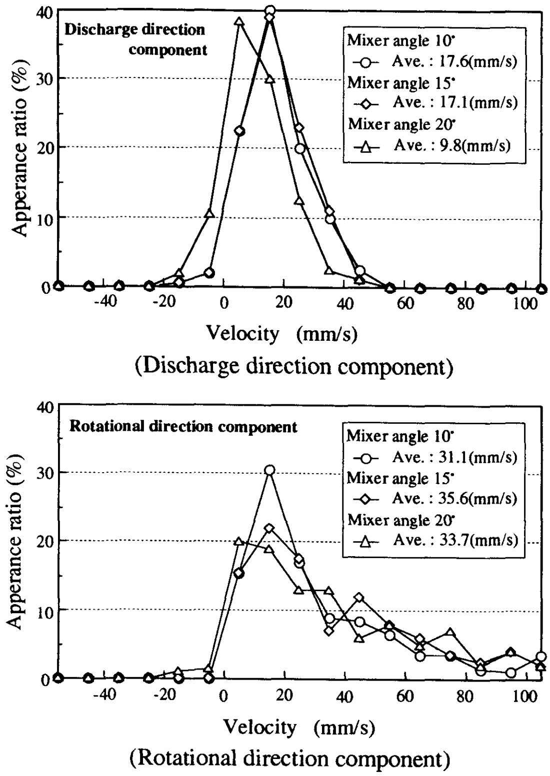


Fig.16 Velocity distribution of each component by mixer angle

increased. This agrees with the common understanding that discharge efficiency is reduced if the mixer is angled upward. The appearance ratio of the rotational direction component tends to indicate the same dispersion and peak position in all cases of mixer angle. The average scarcely increases when the mixer angle is increased. Therefore, it is deduced that increasing the angle of the mixer changes the flow direction of the concrete in the mixer, increases the time of passage through the whole mixer, and does not lead to the partial retention phenomenon.

5. EVALUATION OF MIXING PERFORMANCE BY WASHING ANALYSIS

5.1 Purpose of Experiment

As described above, variations in the arrangement of blades or the paddle blade design can lead to the partial retention phenomenon, while increasing the mixer angle lengthens the time of passage through the mixer. Thus, each of these characteristics affects mixing performance in some way. However, it has not been definitely shown to what degree each affects discharge efficiency and mixing efficiency. Consequently, using the volume ratio of model coarse aggregate to model mortar as an index, the mixing performance was evaluated in accordance with JIS A 1112 "Washing Analysis of Fresh Concrete".

5.2 Experimental Method

Samples were removed from the auger of the model continuous mixer at the points illustrated in Fig.17. The mixer, mixer blades, and model mortar were exactly as before. Thin square acrylic chips (measuring about 2.6 mm on a side and with a specific gravity of 1.16) were used as the model coarse aggregate. The model mortar and coarse aggregate were thrown in alternately 5 seconds apart. The volumetric ratio of model coarse aggregate to model mortar (known as Vg/Vm here) was chosen to be 0.4 after complete mixing. The addition rate was $1*10^{-4}$ m^3/s for correspondence with an actual machine. The model coarse

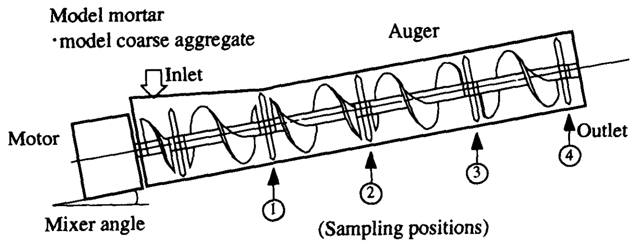


Fig.17 Sample collection

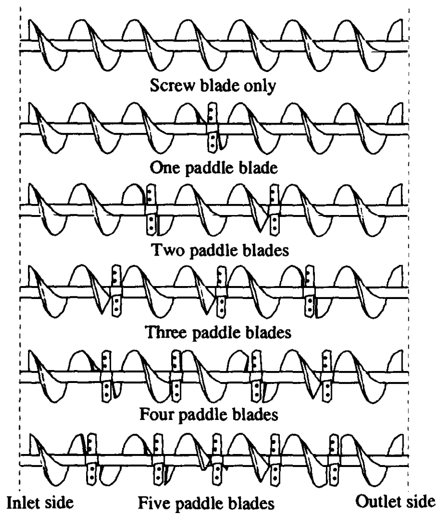


Fig.18 Arrangements with varying number of paddle blades

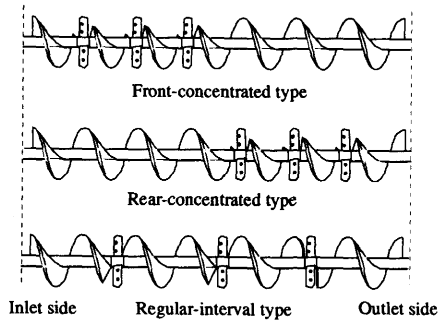


Fig.19 Arrangements of blades at different points

aggregate, Vg/Vm, and the addition rate were chosen so as to obtain the difference in mixing performance with each experimental parameters.

Mixing was halted 25 seconds after the first discharge, and a sample of proper quantity was taken at each of the positions ①-④ shown in Fig.17. Mixing was then started again, and samples were extracted 25 seconds apart in this manner for the total of 5 times. Samples were prepared for washing analysis with a 2.5mm sieve, and the Vg/Vm of the sample was computed. Experimental parameters were the number of paddle blades (using the two-blade design), setting point of paddle blade and slope of mixer. Six blade arrangements were tested, as shown in Fig.18. The three arrangements shown in Fig.19 were also tested to determine the effect of varying the positions of the three paddle blades. Two mixer angles, 10 and 15 degrees, were tested.

In a continuous mixer, concrete added together is not necessarily discharged all at the same time. In this experiment, the passage time through the mixer is defined as the period between adding twenty styrene foam particles and the discharge of three of them.

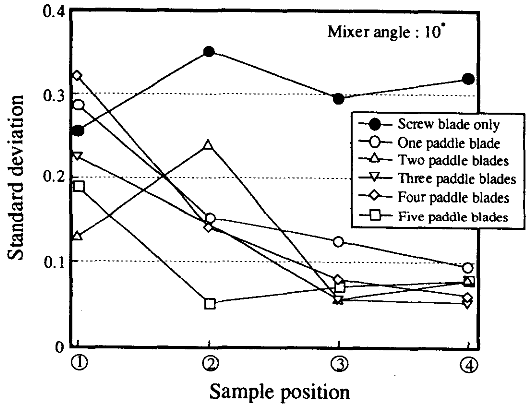


Fig.20 Standard deviation from initial value Vg/Vm=0.4 (mixer angle 10°)

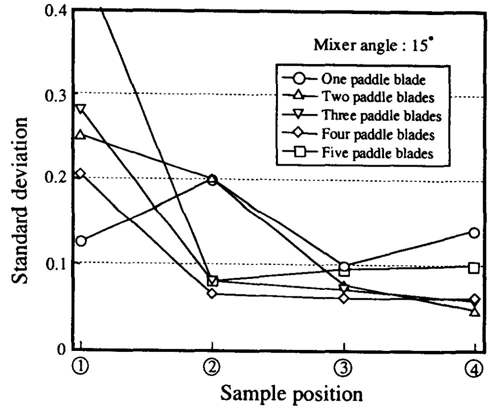


Fig.21 Standard deviation from initial value Vg/Vm=0.4 (mixer angle 15°)

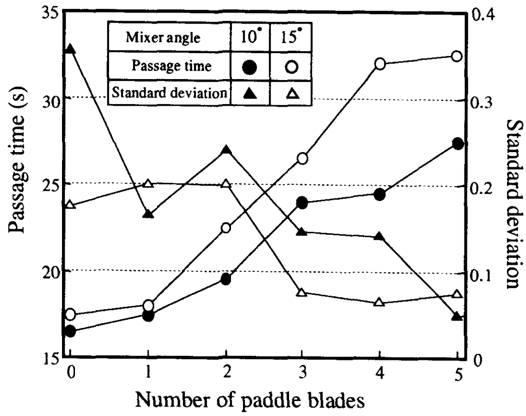


Fig.22 Relationship between number of paddle blades and passage time and standard deviation

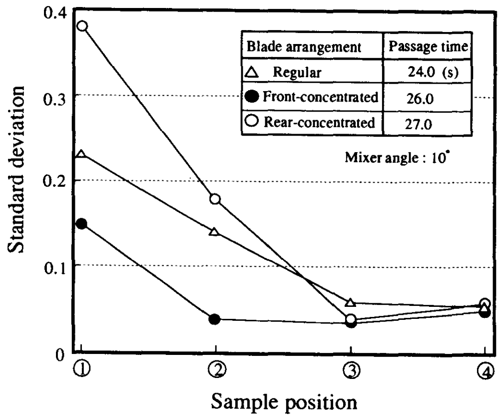


Fig.23 Standard deviation from initial value Vg/Vm=0.4 (three paddle blades)

5.3 Experimental Results and Discussion

Figure 20 shows the standard deviation of samples from the initial value Vg/Vm=0.4 for a 10-degree mixer angle and the blade arrangement shown in Fig.18. In case of a screw blade only, which does hardly any mixing, the standard deviation is large at all sample positions, and it is recognized that Vg/Vm changes greatly. On the other hand, when paddle blades are used, the standard deviation converges at sample position ④ regardless of the number of paddle blades. This suggests that installing one paddle blade only is valid as regards mixing efficiency. The case in which the standard deviation became small within the shortest distance of the inlet is the one with five paddle blades.

According to Uomoto et al.[7], a normal forced-mixing batch mixer first "mingles and disperses" the mix to make the concrete materials uniform when mixing begins, and then "kneads" the concrete. As for the continuous mixer, the "kneading" process is crucial to stable concrete quality. Therefore, in order to make the concrete uniform as soon as possible and to secure retention time that allows the concrete to be "kneaded", increasing the number of paddle blades is important.

The standard deviation from initial value Vg/Vm=0.4 of samples in case of a 15 degree mixer angle is shown in Fig.21. The tendency of the standard deviation to converge is the same as with the 10-degree angle, and the standard deviation became small within a short distance of the inlet with just three paddle blades. However, increasing the mixer angle extends the passage time simply, and it is unknown whether the tendency of the standard deviation to converge provides "kneading" of the concrete.

Figure 22 shows the relationship between the number of paddle blades and the passage time which is related to the discharge efficiency and to the standard deviation at sample position②. The passage time increases simply by increasing the number of paddle blades. In the range of three to five paddle blades, increasing the mixer angle from 10 degrees to 15 degrees results in a longer passage time compared for a given number of paddle blades.

Figure 23 shows the standard deviation from the initial value Vg/Vm=0.4 of samples in the case of a 10-degree mixer angle for the arrangements of blades shown in Fig.19. In the case of the front-concentrated arrangement, the standard deviation became small at sample position② near the inlet. In the case of the rear-concentrated arrangement, the standard deviation converges near the outlet. The regular-interval design may be considered the middle arrangement. The passage time when the paddle blades are concentrated rises, even if the number of paddle blades remains the same. Therefore, it is desirable to place the paddle blades at regular intervals as far as possible once the length of the auger part has been determined.

6. CONCLUSIONS

This paper describes laboratory experiments carried out to investigate the effect of blade arrangement, paddle blade shape, and mixer angle in a continuous mixer on the flow direction and velocity vector of fresh concrete using a visualization technique. Results are as follows :

(1) The flow behavior of concrete in the mixing process in a continuous mixer was evaluated quantitatively using a solid-liquid two phase material as the model concrete.

(2) Paddle blades cause flows in various directions and at varying velocity as compared with one fixed direction and velocity in the case of a screw blade only. As a result, mixing is activated.

(3) Paddle blades reduce flow area in the discharge direction and cause a partial retention phenomenon to occur in the front of the paddle blade. The effect of this partial retention continues for some distance beyond the paddle blade.

(4) For a given number of paddle blades, if the shape of the paddle blade is changed, the discharge efficiency and mixing efficiency also vary.

(5) Increasing the angle of the mixer changes the flow direction of the concrete in the mixer, increases the passage time through the mixer, and eliminates the partial retention phenomenon.

(6) In a continuous mixer, the "kneading" of concrete once it has been made uniform is very important to obtaining stable concrete quality. In order to make the concrete uniform as soon as possible and then secure enough retention time to "knead" the concrete, it is important to increase the number of paddle blades.

The next step is to consider the effect of the shape of a single blade and the dip angle of the paddle blade, and leading to a method of evaluating the best arrangement of mixer blades.

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