- Technical Paper -

THE EFFECT OF LIQUIDITY AND SEGREGATION-RESISTANCE OF FILLING MORTAR

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ABSTRACT
In the construction of retrofitting works with steel jacketing, there is a gap between steel plates and existing bridge pier or column, the anti-earthquake reinforcement would be provided by using filling material to fill up the gap. The fluidity and segregation-resistance property of filling material are the most important part to control the filling. However, it is relatively difficult to prepare and evaluate it. In this study, the evaluation of segregation-resistance property and the rheology of gap filling mortar was conducted on the basis of ensuring the fluidity of filling mortar.
Keywords: filling mortar, aggregate, flow value, segregation-resistance, plastic viscosity

1. INTRODUCTION

In recent years, with the rapid economic development, infrastructure construction is also increasing. Decades later, the infrastructure was built to face maintenance. After the Kobe earthquake in 1995, Japan began to construct the existing seismic reinforcement engineering. After 3.11 earthquake, the number of seismic reinforcement project is increased. In a variety of seismic reinforcement methods, there is a method called Steel Plate Lining. In the construction of retrofitting works with steel jacketing, there is a gap between steel plates and existing bridge pier or column, the anti-earthquake reinforcement would be provided by using filling material to fill up the gap. Therefore, a high quality filling property is required. The fluidity and segregation-resistance property of filling material are the most important part to control the filling. However, it is relatively difficult to prepare and evaluate the filling mortar which met the requirement of two kinds of properties at the same time because of their opposite performance. On the one hand, it is requires that even a small space still can be filled, on the other hand, filling material should also have material segregation-resistance, or in the filling process of aggregate and cement paste segregation will lead to occlusion. Although there has been a lot of proposals for filling experimental methods, but many of them cannot meet the requirements of the applicability, so to accurately evaluate the filling of the experimental method is still not final determination.

In this study, under the same condition of 250(±5%) mm flow value, used a two-cylinder gap filling experimental device to investigate the filling. The filling property of the gap filled mortar was quantitatively evaluated. The liquidity gap filling mortar, material segregation resistance, and aggregate particle size as an important factor influencing the gap filling of the review. The liquidity is mainly based on the value of flow and plastic viscosity. The material segregation-resistance is determined by the settlement of the aggregate and the distribution of the aggregate after the flow test. The flow properties of filling mortar were qualitatively evaluated by four different kinds of experimental methods.

2. EXPERIMENT PROGRAMS

2.1 Experimental Materials

The main experimental materials used are shown below as Table.1.

2.2 Mix proportion

The detailed mix proportion of mortar is provided in Table 2. Viscosity modifying admixtures (VMAs) are water-soluble polymers that increase the viscosity of mixing water and enhance the ability of cement paste to retain its constituents in suspension. From a rheological point of view, the use of a VMA along with adequate high-range water reducing agent (AE) content enables to ensure high deformability and stability. With the increase of the amount of VMAs, plastic viscosity and yield value increased. But With the increase of the amount of high-range water reducing agent (AE), yield value became lower, and plastic viscosity almost unchanged. Using this relationship, by changing the amount of both, make out the mortar with different plastic viscosity,and let the mortar flow value reach 250(±5%)mm. The amount of the mixture is illustrated

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in Table.2. Mixed the cement and the dry fine aggregate, then put it into the room where is 20℃.

2.3 Experimental Project

Table.3 presented the experiment project used in this study.

(1) Viscosity test

Rotary viscometer is an instrument used to measure the viscosity of a fluid. Viscometers only measure under one flow condition. In general, either the fluid remains stationary and an object moves through it, or the object is stationary and the fluid moves past it. The drag caused by relative motion of the fluid and a surface is a measure of the viscosity. The flow conditions must have a sufficiently small value of Reynolds number for there to be laminar flow. At 20.00 degrees Celsius the dynamic viscosity (kinematic viscosity x density) of water is 1.0038 mPa·s and its kinematic viscosity (product of flow time x Factor) is 1.0022 mm2/s. These values are used for calibrating certain types of viscometers [1].

(2) Double cylinder system gap filling test

In this study, according to previous studies, As Fig.1, The double cylinder system gap filling test apparatus were used to do the experiment. The device was composed of two layers of acrylic fibber pipes (inner pipe and outer pipe), outer pipe has three different diameters, and void width were 2mm, 3mm and 5mm. First, poured the experimental material into the inner pipe to the height of 450mm and rest for one minute. Then, lift the inner pipe, and the height of that was the same as the void width. It was called filling height. The material in the inner pipe and the outer pipe were of the same height, the height was called the theoretical filling height. The ratio of the filling height to the theoretical filling height was called gap filling rate [2].

(3) Flow test

Similar to slump, mortar flow is a relative measure of workability. Changes in flow indicate variability in the materials and/or the batching process that may not be observed from slump testing alone. Mortar flow is most sensitive to water content and air content. It is also more sensitive than the slump test for stiff concrete mixtures. Mortar flow is a process control test procedure and should not be considered as an acceptance criteria.

Water content, fine aggregate gradation, cementitious chemistry, mixing time, air content, and concrete temperature all interact to affect mortar flow. A flow test cannot identify which of these factors is changing it simply measures the flow of a given mortar.

Uniformity of the mortar flow is the primary concern. In the construction site, flow experiments are usually used to evaluate the flow properties of the filling materials. In this study, according to the Building Renovation Supervision Guidelines and JSCE-516 of provisions of table flow test, a cylinder which is made of polyvinyl chloride pipe was used in the flow test, the inner diameter is 50mm and height is 100mm [3] the equipment of flow test and step flow test are shown in

Table 1. The main experimental materials

cement	Portland Cement	
	Density:3.16(g/cm^3), Specific surface area:3300(cm^2/g)	
Fine aggregate	Limestone crushed sand	Particle size: Small ＜1.2mm
	Dry density:2.54 (g/cm3)	Particle size: Medium 1.2mm～2.5mm
	Water absorption: 1.5%	
High - range water reducing agent (AE)	Polycarboxylic acid ether type	
Viscosity modifying admixtures	Methyl cellulose ether type(Aqueous solution viscosity 190～350mpa·s)	
Antifoaming agent	Polyalkylene glycol derivatives	

Table 2. Mix proportion of the test

W/C	S/C	W	C	S ＜1.2mm	S ≧1.2mm	VMAs (W×%)	AE admixture (C×%)	Antifoaming agent:
0.4	0.8	388	969	621	156	0.30	1.9	C×0.05%
						0.45	2.2	
						0.45	2.0	
						0.10	1.0	
						0.10	0.7	
						0.08	0.7	

Table 3. Experimental Project

Test	Evaluation index	Experimental method
Viscosity test	Plastic viscosity	JIS Z 8803
	Yield value	
Double cylinder system gap filling test	Gap filling ratio	Descriptive records
Flow test	Flow(glass)	JASS 15M-103/ JHS 313-1999
	Step flow(Acrylic)	
JP funnel test J14 funnel test	Flow time	JSCE F541 JSCE F543
Segregation resistance test	In horizontal direction way (SR_H)	Descriptive records
	In vertical direction way (SR_V)	

Fig 2.

Pour the experimental material into the cylinder, then lift it. Measurement of time when the mortar reach 250mm, after 3 minutes, the diameter of the two right angles was measured with ruler, and the average value was obtained as the flow value. The segregation-resistance of material in horizontal direction can be obtained through Step Flow test. The experimental method is the same as flow test are shown in Fig.3.

Weighing the 1.2mm particle size aggregates in (a) and (b) after drying. The unit volume weight of large particle size aggregate were $X/\{(r^2-75^2)\pi\}$ g/cm^2, $(Y/75^2\pi)$ g/cm^2, the segregation-resistance of material in horizontal direction is SR_H [4].

$$SR_H = X/\{(r^2-75^2)p\}/(Y/75^2 p) \qquad (1)$$

(4) J funnel test

The JP funnel test was performed according to baseline JSCE-F 541,and the J14 funnel test was performed according to baseline JSCE-F 531. J14 funnel and segregation-resistance method is shown as Fig.4. The test procedure was to first support the funnel vertically and wet it through water. Poured the sample into the funnel, allowed a suitable amount of sample to flowed out from the outlet, hold down the outlet with fingers, poured the sample to the top, then level the top. Release the fingers and let the mortar flow out, recording the time the material flowed from the beginning to the outage. When too much material remained in the funnel, the test material was considered unwell. The reason for the residue may be that the aggregate is blocked. The experiment was carried out twice and the average was taken as the experimental data. (When the first and the second runoff time has large difference, the experiment carried out three times.)

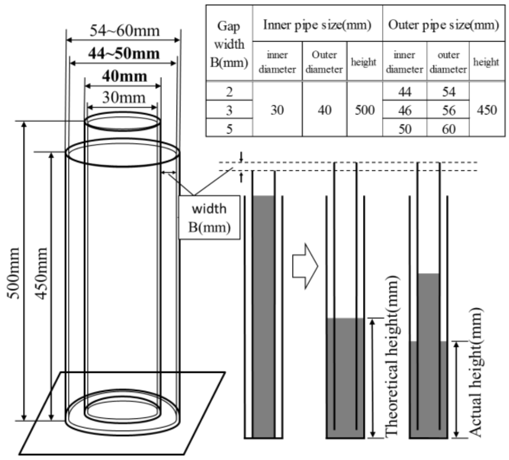
The segregation-resistance of material in vertical direction can be obtained through J funnel test. High plastic viscosity inhibits the settlement of aggregate, the segregation-resistance of material get higher. First, poured the experimental material into the funnel, placed for 1 minutes, let the experimental materials flowed out of 200ml (A), then flowed out the rest part 430ml (B). Wash these two parts separately. Weighing the 1.2mm particle size aggregates in (A) and (B) after drying. As it shown in figure3, the unit volume weight of large particle size aggregate were (X/200) g/ml, Aggregate volume 1ml contains 156/1000. Used initial sample to calculate, the segregation-resistance of material in vertical direction as SR_V.

$$SR_V=(X/200) / (156/1000) \qquad (2)$$

3. RESULTS AND DISCUSSIONS

3.1 Experimental results

In this study, in order to investigate the relationship between materials segregation-resistance property and the rheology of gap filling mortar condition was determined that the flow value reach to 250(±5%) mm, then selected the data that meet the conditions. The experimental results shown as Table.4.



Gap width B(mm)	Inner pipe size(mm)			Outer pipe size(mm)		
	inner diameter	Outer diameter	height	inner diameter	outer diameter	height
2	30	40	500	44	54	450
3				46	56	
5				50	60	

Fig.1 The double cylinder system gap filling test apparatus [5]

Fig.2 The equipment of flow test and step flow test

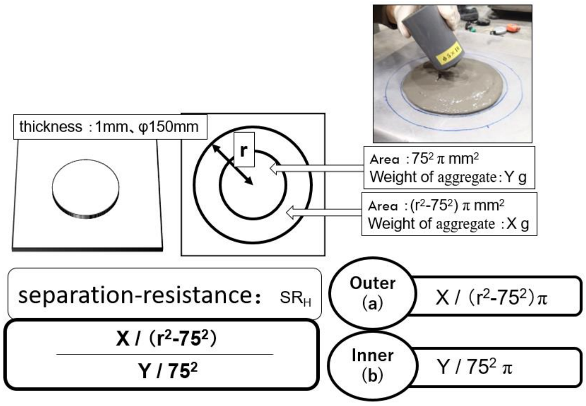


Fig.3 The method of segregation-resistance

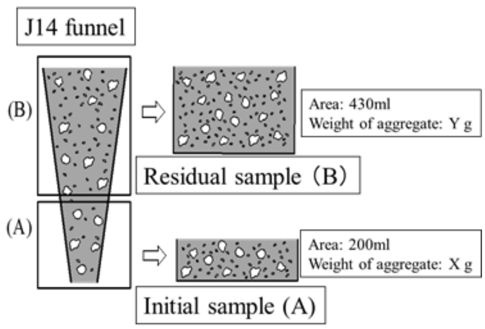


Fig.4 J14 funnel and segregation-resistance method

Table 4. The experimental results

	AE admixture (C×%)	VMAs (W×%)	flow (mm)	Step flow (mm)	JP funnel (s)	J14 funnel (s)	SRv	SR_H	Filling ratio (%) 2mm	3mm	5mm	Plastic viscosity (mPa・s)	Yield value (Pa)
No.1	1.9	0.30	271.0	281.5	15.09	8.57	0.81	1.40	28.7	85.0	97.7	3636.8	22.15
No.2	2.2	0.45	255.0	276.0	18.06	11.23	0.81	1.68	27.0	83.8	92.5	4988.8	30.38
No.3	2.0	0.45	256.0	278.5	17.61	11.38	0.93	1.47	53.1	86.0	95.1	5004.8	35.18
No.4	1.0	0.10	267.5	281.5	10.47	9.82	0.99	1.31	39.7	95.5	100.0	2355.2	24.86
No.5	0.7	0.10	242.5	258.0	11.97	11.47	1.22	1.26	33.1	92.8	100.0	2817.6	26.75
No.6	0.7	0.08	230.0	246.0	11.73	11.30	1.00	1.13	23.0	91.0	99.5	3220.8	31.21

3.2 Effect of the amount of viscosity modifying admixtures and high - range water reducing agent (AE) on plastic viscosity

By adjusting the amount of viscosity modifying admixtures and high-range water reducing agent (AE) to produce the flow value for 250(±5%) mm of the experimental materials.

Fig.5 showed the relationship between viscosity modifying admixtures and AE admixture of mortar. According to Miyamoto [5], yield value and plastic viscosity increase as the addition amount of the viscosity modifying admixtures increases, the yield value decreases when the addition amount of the AE admixture is increased, but the change amount of the plastic viscosity is small. It is generally known that with the increase of amount of viscosity modifying admixtures, plastic viscosity also increased, yield value almost unchanged. Add a large amount of high-range water reducing agent (AE), in order to make the flow value reach 250(±5%) mm, with the amount of viscosity modifying admixtures increased, the amount of high-range water reducing agent (AE) was increased too.

3.3 Relationship between filling ratio and plastic viscosity

The relationship between the gap filling and the plastic viscosity as shown in Fig.6. In this experiment, the maximum filling height is 335mm, in order to satisfy the independent filling, the filling height is more than 300mm. In this case, the filling rate is 89.6% according to the filling height and the theoretical filling height. In this study, 90% as the experimental target. The filling ratio of gap width of 5mm was all above 90%, however the filling ratio of gap width of 3mm were less than 90%, With the increase of plastic viscosity, viscosity resistance due to the filling ratio decreased. The reason for this is that the greater the viscosity, the greater the viscous resistance of the gap.

width is 2mm, Due to the maximum particle size is There is another reason for underfill when the gap larger than the gap width 2mm, and the filling is not complete. The maximum size of aggregate and the gap Width is almost same, the filling rate is still low,this proves that in the process of filling aggregate blocked, and caused the filling rate cannot reach to 90%.

Based on the experimental results, the relationship between void filling ratio and plastic viscosity is calculated.

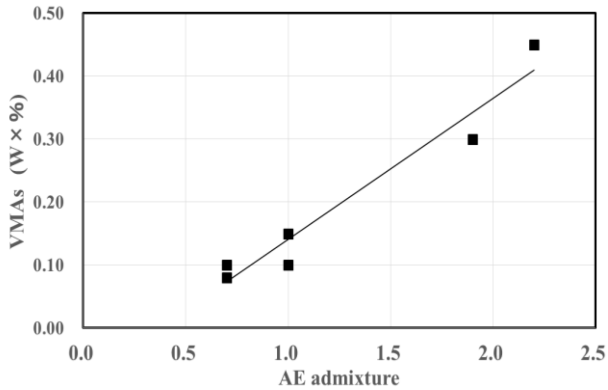


Fig.5 Relationship between VMAs and AE admixture of mortar

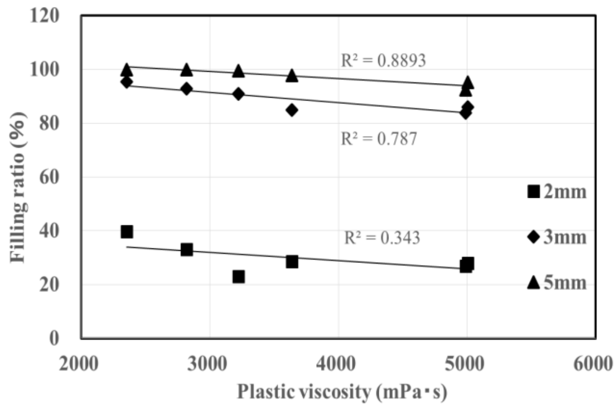


Fig.6 Relationship between filling ratio and plastic viscosity of mortar

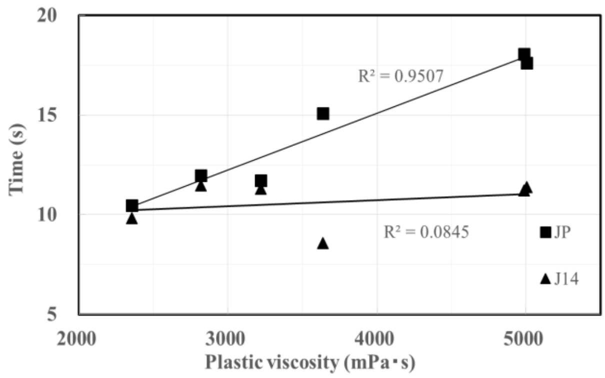


Fig.7 Relationship between flow-down time and plastic viscosity of mortar

$$Y_3 = -0.0046X + 105.17$$
$$Y_5 = -0.0031X + 108.20$$

Y_3 : Filling ratio of gap 3mm.

Y_5 : Filling ratio of gap 5mm.

Calculate the upper limit value of plastic viscosity 3mm is 3298 mPa・s and 5mm is 5871 mPa・s.

3.4 Relationship between flow-down time and plastic viscosity

The relationship between the flow-down time and plastic viscosity as shown in Fig.7. As can be seen from the figure, with the increase of plastic viscosity, flow-down time is also increased. Using the same experimental material, the flow-down time of two different kind of funnel are not the same, because compared with the J14 funnel, JP funnel has a straight tube part, and flow-down time will be longer. Therefore, it is possible for the JP funnel to show clearly the difference in liquidity than the J14 funnel. As the plastic viscosity increases, it is difficult to judge the timing at which the sample flows out, and it is easy for measurement errors to occur, so it is necessary to take a video.

3.5 Relationship between segregation resistance of vertical direction and plastic viscosity

The relationship between segregation resistance of vertical direction and plastic viscosit as shown in Fig.8. As can be seen from the figure, with the increase of plastic viscosity, vertical direction of segregation resistance value is decrease. This result is consistent with previous studies. The material is not separated on vertical direction when the value of SR_V is close to 1.00. However,With the plastic viscosity increases, the value of SR_V become smaller. When plastic viscosity is less than 3200, the segregation resistance value of mortar is close to 1.00. This reason also needs to be reviewed.

Fig.9 showed the relationship between vertical direction of segregation resistance and yield value. As can be seen from the figure, with the increase of yield value, vertical direction of segregation resistance value did not change at all. Comparing with the data of the filling experiment, it can be seen that the yield value only have a small part to play in vertical direction of segregation resistance.

3.6 Relationship between segregation resistance of horizontal direction and plastic viscosity

In this study, focusing on the segregation resistance of horizontal direction. The relationship between the SR_H and plastic viscosity as shown in Fig.10. As can be seen from the figure, with the increase of plastic viscosity, segregation resistance of horizontal direction value is also increasing. This result is consistent with previous studies. The material is not separated on horizontal direction when the value of SR_H is close to 1.00. However, with the plastic viscosity increases, the value of SR_H is greater than 1.00. It is clear that when plastic viscosity is larger, SR_H is also far from 1.00, the filling effect is also significantly decreased. When plastic viscosity is less than 3298, the segregation resistance

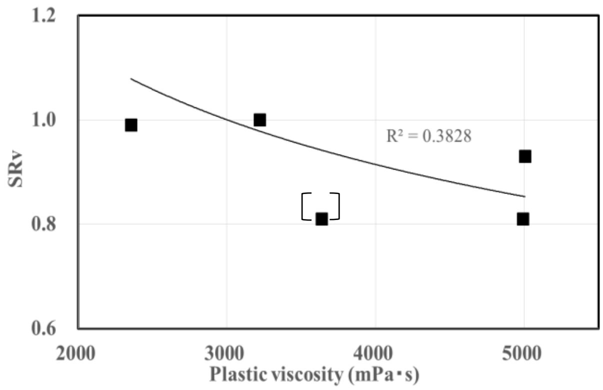


Fig.8 Relationship between vertical direction of segregation resistance and plastic viscosity

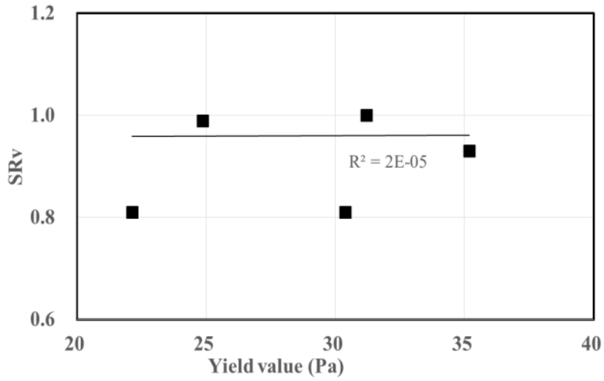


Fig.9 Relationship between vertical direction of segregation resistance and Yield value

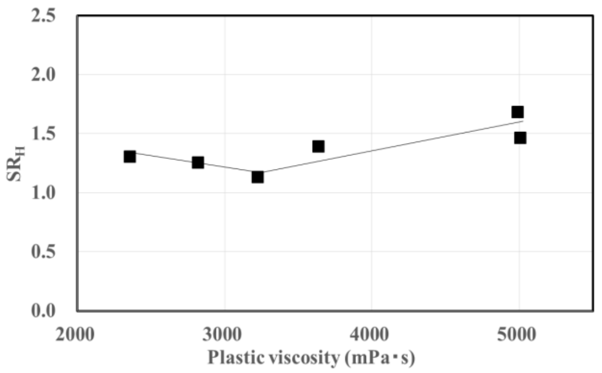


Fig.10 Relationship between segregation resistance of horizontal direction and plastic viscosity

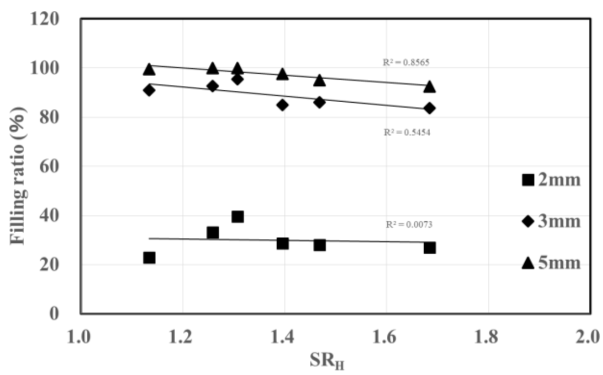


Fig.11 Relationship between segregation resistance of horizontal direction and filling ratio

Fig.12 Comparison of experimental results of No.2 and No.5

value of mortar is close to 1.00.

Fig.11 showed the relationship between segregation resistance of horizontal direction and filling ratio. As can be seen from the figure,in case of void width are 3mm and 5mm with the increase of segregation resistance of horizontal direction value, filling ratio is decreased slightly. Therefore, the filling rate is directly related to the segregation resistance of horizontal direction value.

As can be seen from Fig.12 the material is separated, it is obvious that the middle part of the experimental material is in different colors. The phenomenon of Fig.12 tallies with the experimental results, SR_H =1.68(NO2.) and SR_H =1.26(NO5) On the contrary, the vertical direction of segregation resistance during the experiment cannot be seen directly.

4. CONCLUSIONS

Different mix proportion were used in this study. The main purpose was under the same condition of 250(±5%) mm flow value, the evaluation of materials segregation-resistance property and the rheology of gap filling mortar was conducted on the basis of ensuring the fluidity of filling mortar. The conclusions drawn from the experimental results are as following:

(1) The results can be proved by experiment that with the increase of the amount of viscosity modifying admixtures, plastic viscosity and yield value increased. But With the increase of the amount of high-range water reducing agent (AE), yield value became lower, and plastic viscosity did not changed at all.

(2) Through the experimental results can be known that adding the mixture too much, has a negative impact on the filling, the aggregate particle size has influence on the filling.

(3) With the increase of plastic viscosity, segregation resistance of horizontal direction value is also increasing. When plastic viscosity is less than 3298, the segregation resistance value of mortar is the best. But there is no clear evaluation index for the segregation-resistance of mortar. In the future, it is necessary to improve the experimental methods and evaluation methods of horizontal direction and vertical direction of segregation resistance.

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