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Research Article

Experimental Investigation of the Influence of Cellulose Ether on the Floating of Rubber Particles in Mortar

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As a kind of hyperelastic material, rubber can be mixed into mortar (or concrete) to improve the anticracking ability and ductility of concrete. The mixture of rubber can change the internal structure of concrete through physical interaction, without changing the chemical properties of each component in the mortar (or concrete). But since the apparent density of rubber is far less than the density of cement-based materials, rubber particles are likely to separate from cement-based materials in the mixture of rubber and mortar, and consequently, rubber particles will float upward. This study proposes a new method to restrain the rubber particles from floating upward: add cellulose ether in the mortar with a water-cement ratio of 0.45 so as to improve the mobility of mixture. Meanwhile, this study employs the method of quadratic orthogonal rotation combination experiment to carry out research on the influence of the mixing amount of cellulose ether (0~5.43 kg/m^3) and the ratio of rubber substituting for mortar (0~0.5) on the degree of uniformity, consistency, and 28-day (28 d) strength of crumb rubber mortar, and it also studies the inhibiting effect of cellulose ether on the floating of rubber. The results show that cellulose ether mixed into the mortar can significantly improve the mobility of the mixture and restrain the floating of rubber. But with the increase of the mixing amount of cellulose ether, the 28 d strength of the mortar shows an obvious decreasing trend. This study has a guiding role in the practical application of crumb rubber mortar, crumb rubber concrete, and other lightweight aggregate concrete.

1. Background

As a kind of hyperelastic material in crumb rubber mortar (or concrete), rubber can be mixed into the mortar (or concrete) to change the internal structure of concrete through physical interaction, without changing the chemical properties of each component in the mortar (or concrete). Research studies [1] show that rubber particles can improve the anticracking ability and ductility of concrete, and when crumb rubber mortar is damaged, brittle fracture will not happen suddenly. Pelisser et al. [2] found that the density of concrete mixed with rubber decreases by 13% compared with that of normal concrete. Yilmaz and Degirmenci [3] concluded from research that when rubber is mixed into concrete in the form of fiber, the bending strength of concrete increases by 20%, and with the continuous increase of rubber, the bending strength shows a downward trend. Besides, normal concrete presents brittle fracture while rubberized concrete presents ductile fracture. Kang et al. [4] found that concrete sample containing rubber particles will produce obvious plastic deformation during the bending process, and it will not produce plastic fracture when sustaining the peak load, but produce ductile fracture after big plastic deformation. Research studies carried out by Thomas et al. [5] indicate that the carbonation depth of concrete mixed with rubber is smaller than that of normal concrete. Raghavan et al. [6] mixed rubber with a mass proportion of 0.6% into the concrete, and the result showed that the rubberized concrete has a minimum mass loss in the freeze-thaw test. Oikonomou and Mavridou [7] revealed that the infiltration capacity of chloride ion decreases with the increase of rubber. The concentration of chloride ion in the rubberized concrete with various mix proportions in the research conducted by Gupta et al. [8] is very low, which shows that crumb rubber concrete has a very good permeation effect for chloride ion. Research of Thomas et al. [5] indicates that the depth of penetration of chloride ion in the concrete mixed with 10% rubber is smaller than that of normal concrete. In summary, rubber particles mixed into the concrete, on the one hand, overcome many defects of concrete material, such as big self-weight and brittleness. On the other hand, it expands the application fields of waste rubber, realizes reasonable cyclic utilization of resources, and gains high economic and social benefit [1].

Apparently, the density of rubber is far smaller than the density of cement-based materials, which will certainly result in the separation of rubber particles in the mixture from cement-based materials. Wang et al. [9] conducted an orthogonal experiment and explored different factors that influence the floating of rubber particles in crumb rubber lightweight aggregate concrete. The research shows that there exist complex factors influencing the floating phenomenon of rubber particles, and the main factors are water-binder ratio and the size of rubber particles. As for research studies on preventing rubber particles from floating upward in cement-based materials, the methods mainly include adjusting the mix proportion of cement-based materials and controlling the dosage of cementing material. Turatsinze and Garros [10] mixed a certain dosage of superplasticizer (the mixing amount is $3.5\,kg/m^3 \sim 9.32\,kg/m^3$) in crumb rubber concrete, achieved uniform distribution of rubber particles in self-compacting rubberized concrete, and avoided floating phenomenon. Kang et al. [11, 12] proposed the concept of roll-compacted crumb rubber concrete and carried out systematic analysis of its properties, preventing rubber particles from floating upward in the cement-based materials in the plastic state. Zhu et al. [13] adopted three indexes, i.e., compressive strength and density of the upper, middle, and lower prism specimens and the distribution of rubber particles of the specimen at the cross section to represent the floating of crumb rubber in the concrete, and prevented rubber from floating by adding superabsorbent polymer (SAP) to the mixture. But this method lowers down the service performance of concrete. Some other scholars [14–17] studied the relationship between rubber floating and the vibration time and improved the uniformity of rubber particles through the control of vibration time of the mixture. Although this method can improve the uniformity of rubber particles, it reduces the vibration time and increases bubbles in the concrete, resulting in insufficient compaction rate of concrete. The cellulose ether is a polymer compound having an ether structure made of cellulose. Due to its molecular structure, the cellulose ether can be used as thickening and water-retaining agents [18]. The addition of cellulose ether could affect the mechanical strength of the mortar and the hydration of cement. The 28 d strength of the mortar shows a decreasing trend with the increase of cellulose ether [19]. With the increase of cellulose ether, the condensation time of cement slurry is prolonged: the initial condensation time is not obvious, but the final condensation time is significantly prolonged with the increase of cellulose ether [20].

This study adds cellulose ether in the mortar so as to improve the mobility of the mixture and restrain the rubber particles from floating upward. It employs the method of quadratic orthogonal rotation combination experiment to study the inhibiting effect of cellulose ether on the floating of rubber, including 16 groups of molded specimens, 3 samples in each group.

2. Experiment Design

2.1. Materials. In order to reduce the influence caused by materials, the concrete admixtures adopted by this experiment include the reference cement special for inspection of concrete admixture and China ISO standard sand. As for cement, it adopts P·I 42.5 Portland cement manufactured by Shandong Lucheng Cement Co., Ltd (it can be found in the supplement document). Its chemical components are shown in Table 1, and physical and mechanical properties are shown in Table 2. As for sand, it adopts China ISO standard sand manufactured by Xiamen ISO Standard Sand Co., Ltd., and the particle size index is shown in Table 3. Rubber particles are produced by mechanically grinded waste rubber, with 40 meshes. Its chemical components are shown in Table 4.

The water-reducing agent used in this experiment is polycarboxylic acid high-performance water-reducing agent (slow solidification type), with a water-reducing rate of 27%. The cellulose ether is hydroxypropyl methylcellulose (MK-20000S) produced by Henan Tiansheng Chemical Industry Co., Ltd; water used is tap water.

2.2. Design of Mix Proportion. Orthogonal experimental design is an efficient, fast, and economical experimental design method for the multifactor and multilevel studies. It is based on the orthogonality to select some representative points from the comprehensive test [21]. The experiment adopts quadratic orthogonal rotation combination and chooses two factors, namely, mixing amount of cellulose ether and ratio of rubber substituting sand. That is, $m = 2$. The asterisk arm r is one experiment factor parameter of orthogonal experiment design, and from the Appendix Table 14-1 in [22], it is easy to know asterisk arm $r = 1.414$ and the number of group of zero level point $m_0 = 8$. According to the requirement of orthogonal experiment design, this experiment adopts 16 groups of test points, including 8 non-zero level test points and 8 zero level test points, 3 specimens for each group. The distribution of test points in the factor space is shown in Figure 1. This experiment substitutes rubber for sand with the same volume to study the effect of ratio of rubber substituting sand, the maximum substitution rate is 0.5, and the minimum substitution rate is 0. The water-cement ratio is 0.45 [14, 23].

The upper limit of cellulose level (X_1) is 5.43 kg, lower limit is 0, and zero level is $X_{10} = (5.43 + 0)/2 = 2.715$ kg. The change interval of cellulose $\Delta j_1 = (5.43 - 2.715)/1.414 = 1.9201$ kg, upper level $= X_{10} + \Delta j_1 = 4.6351$ kg, and lower level $= X_{10} - \Delta j_1 = 0.7949$ kg.

Table 1: Chemical components of the reference cement.

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_2	Na_2Oeq	f-CaO	Loss	CL−
22.19	4.48	3.23	63.10	2.41	2.57	0.53	0.88	2.03	0.013

Table 2: Physical properties of the reference cement.

Type	Compressive strength		Breaking strength		Density (g/cm^3)	Specific surface area (m^2/kg)	Standard consistency (%)	Stability (mm)
	3 d	28 d	3 d	28 d				
P·I 42.5 Portland cement	27.2	51.2	≥3.5	≥6.5	3.16	342	26.4	0.1

Table 3: Technical data of particle size of China ISO standard sand.

Aperture of square hole sieve (mm)	0.65	0.40	0.25
Accumulated weight of screen residue (%)	2.5%	42.6	95.2

Table 4: Technical data of rubber powder.

	Average particle size (μm)	Size of sieve mesh (μm)	Screen residue (%)	Ash content (%)	Acetone extract (%)
40 meshes	367	425	≤10	≤8	≤8

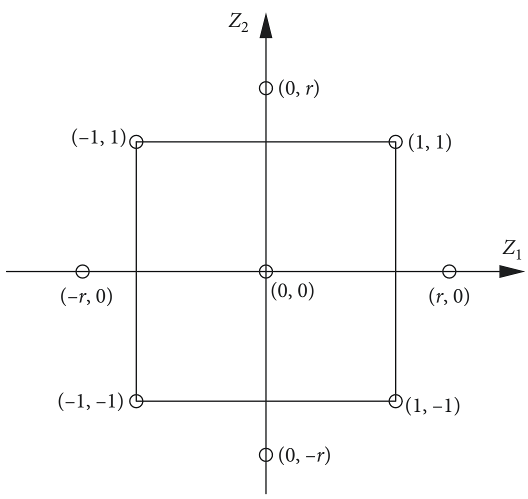

Figure 1: Distribution of test points in the factor space in two-factor combination experiment.

The upper limit of ration of rubber substituting sand (X_2) is 0.5, lower limit is 0, and zero level is $X_{20} = (0.5 + 0)/2 = 0.25$. The change interval of rubber $\Delta j_2 = (0.5 - 0.25)/1.414 = 0.1768$, upper level $= X_{20} + \Delta j_2 = 0.4268$, and lower level $= X_{20} - \Delta j_2 = 0.0732$.

Then, the experiment is designed based on the above theory and methods. The coding schedule of level of factor is shown in Table 5, and the design of experimental scheme and mix proportion is illustrated in Table 6.

2.3. Experimental Method. The experiment in this paper measures the degree of consistency and 28 d strength after molding of the mixture, as well as the degree of uniformity of distribution of rubber particles at the cross section.

Table 5: Coding schedule of level of factor.

Canonical variable z_j	Natural variable x_j	
	Mixing amount of cellulose X_1 (kg)	Substitution rate of rubber X_2 (%)
Upper asterisk arm r	5.43	50% (432 kg)
Upper level 1	4.64	42.68 (368.76 kg)
Zero level 0	2.72	25% (216 kg)
Lower level −1	0.79	7.32% (63.24 kg)
Lower asterisk arm $-r$	0	0 (0 kg)
Interval of change Δj	1.92	17.68% (152.76 kg)

The experiment uses consistency to study the mobility of the mortar. Consistency refers to the performance of mortar that is apt to flow under its self-gravity or external force. The amount of consistency is expressed by sinking degree (mm), and the test apparatus is a mortar consistency tester. In general, big consistency of cement mortar indicates large water content in the mortar. Therefore, the larger the consistency of cement mortar is, the better the mobility of the mortar will be. The measured sinking degree of drop hammer into mortar is used as the index for assessing the consistency of mortar. During the measurement, measure twice for each group of cement mortar material with different mix proportions, take the arithmetic mean value of two experimental results as the final experimental result, and accurate to 1 mm. If the difference between two experimental values is larger than 10 mm, you should carry out resampling for measurement.

Carry out the consistency experiment of rubber cement mortar according to JGJ/T70-2009 Standard for Test Method of Basic Performance on Building Mortar. The test apparatus is shown in Figure 2.

Table 6: Design of experimental scheme and mix proportion.

Number	z_1	z_2	Mixing amount of cellulose X_1	Substitution rate of rubber X_2	Cement (kg)	Water-cement ratio	Sand (kg)	Rubber (kg)	Water-reducing agent (kg)
1	1	1	4.64	0.43	720	0.45	619.06	184.38	10.8
2	1	−1	4.64	0.07	720	0.45	1000.94	31.62	10.8
3	−1	1	0.79	0.43	720	0.45	619.06	184.38	10.8
4	−1	−1	0.79	0.07	720	0.45	1000.94	31.62	10.8
5	−1.414	0	0.00	0.25	720	0.45	810.00	108.00	10.8
6	1.414	0	5.43	0.25	720	0.45	810.00	108.00	10.8
7	0	−1.414	2.72	0.00	720	0.45	1080.00	0.00	10.8
8	0	1.414	2.72	0.50	720	0.45	540.00	216.00	10.8
9	0	0	2.72	0.25	720	0.45	810.00	108.00	10.8
10	0	0	2.72	0.25	720	0.45	810.00	108.00	10.8
11	0	0	2.72	0.25	720	0.45	810.00	108.00	10.8
12	0	0	2.72	0.25	720	0.45	810.00	108.00	10.8
13	0	0	2.72	0.25	720	0.45	810.00	108.00	10.8
14	0	0	2.72	0.25	720	0.45	810.00	108.00	10.8
15	0	0	2.72	0.25	720	0.45	810.00	108.00	10.8
16	0	0	2.72	0.25	720	0.45	810.00	108.00	10.8

Figure 2: Mortar consistency tester.

In this experiment, the uniformity index of distribution of rubber is calculated by means of stratified statistics of distribution area of rubber particles. During this experiment, first take a test specimen, put it on the press machine, and split it in half longitudinally. Then, use a DSLR camera to take high-definition photographs and conduct image processing and vectorization so as to get a clear distribution of rubber particles along the direction of height of the test specimen. It extracts the number and area of vectorized rubber particles and quantifies the distribution of rubber particles as the uniformity index of distribution of rubber. The processing flow of the uniformity index of distribution of rubber is shown in Figure 3.

The uniformity index of distribution of rubber divides the test specimen into three layers, i.e., upper layer (A), middle layer (B), and lower layer (C) [13]. Conduct divisional statistics based on the center of form of rubber particles. Take the specific value of pixel area as the calculation basis of index of uniformity, namely, $\text{Area}_C * 2/(\text{Area}_A + \text{Area}_B)$. As for the 8th group of mix proportion, since the substitution rate of rubber for sand is zero, take the specific value of sinking degree of sand in the mixture as the uniformity index, namely, $\text{Area}_A * 2/(\text{Area}_C + \text{Area}_B)$.

3. Experimental Results and Discussions

Experiment table and results of binary quadratic orthogonal rotation combination is shown in Table 7. Based on the experimental results, carry out significance analysis of regression coefficient and remove nonsignificant items, and establish regression equation for different indexes. To express the results clearly, this paper gives the schematic diagram of curved surface of equation and the corresponding contour map. In addition, as for the single-factor effect analysis in this paper, the method of descent is adopted by fixing one factor at zero level and carrying out single-factor analysis for the other factor.

3.1. Analysis of Uniformity Influence. Carry out variance analysis of influence factor on uniformity, as shown in Table 8.

Get rid of the nonsignificant item whose P value is bigger than 0.1, and we can get the simplified regression equation: $Y = 1.22750 + 0.31953X_1 - 0.20407X_2 - 0.15750\ (X_1)^2$.

Adopt the method of descent for the established regression model, fix the substitution rate of rubber at zero level, and we can obtain the single-factor model of mixing amount of cellulose ether. The curve of single-factor effect analysis of mixing amount of cellulose is shown in Figure 4. With the increase of the mixing amount of cellulose ether, the uniformity of rubber distribution presents a parabola-shape increasing trend. It indicates that when the

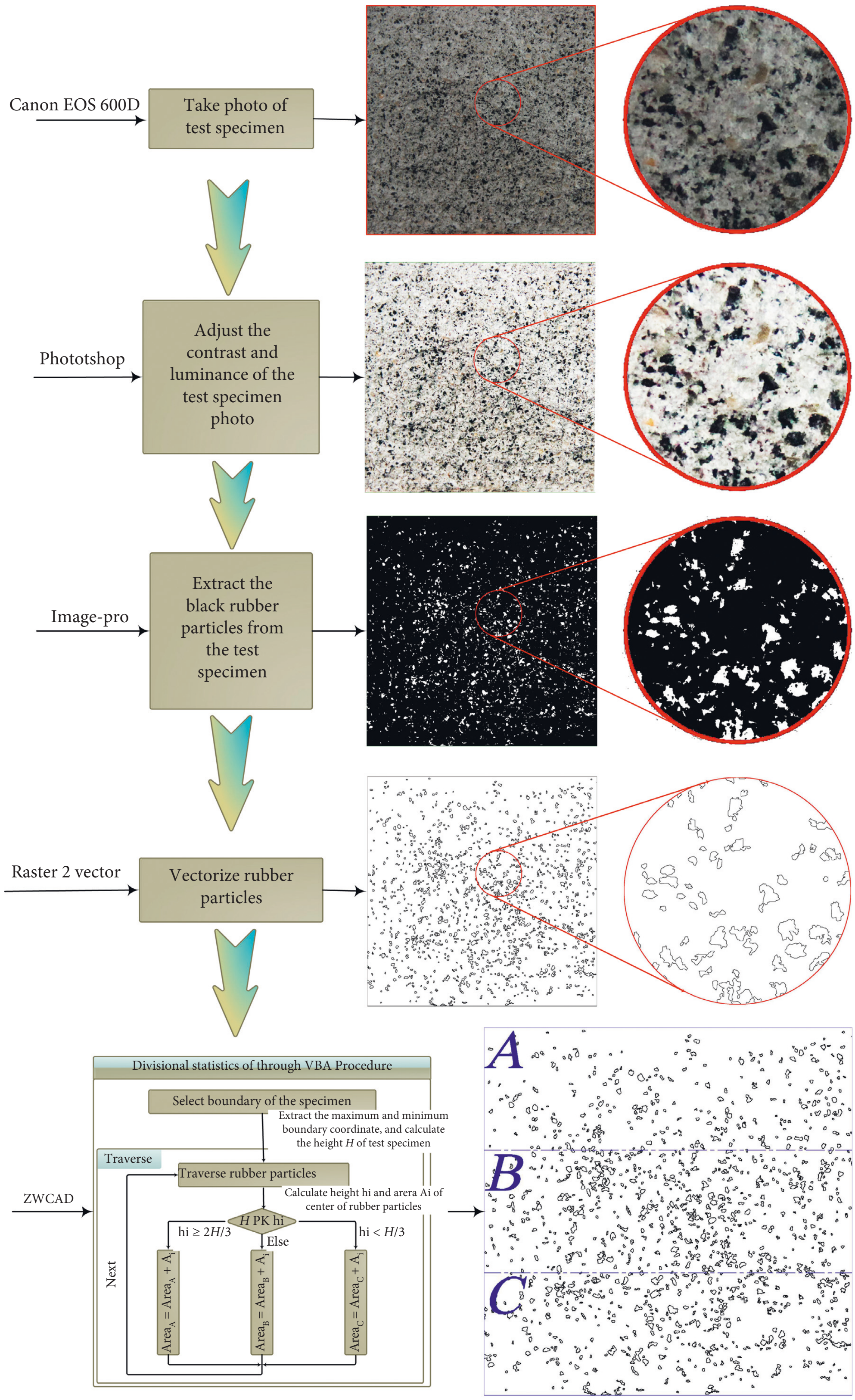

Figure 3: Flowchart of calculation of rubber uniformity.

substitution rate of rubber is at zero level, the increase of the mixing amount of cellulose ether can significantly increase the uniformity of rubber distribution. Meanwhile, when the mixing amount of cellulose ether is above −0.5 (1.75 kg/m^3), the uniformity of rubber distribution reaches 1 and rubber is considered uniformly distributed.

Table 7: Designed experimental data of binary quadratic orthogonal rotation combination.

Number	z_1	z_2	Consistency (mm)	28 d strength (kN)	Uniformity index
1	1	1	57	12.31	1.16
2	1	−1	62	19.8	1.8
3	−1	1	102	13.46	0.54
4	−1	−1	108	30.67	1.08
5	−1.4142	0	110	28.86	0.32
6	1.4142	0	50	15.39	1.18
7	0	−1.4142	80	29.76	1.05
8	0	1.4142	65	10.82	0.73
9	0	0	73	15.09	1.25
10	0	0	79	16.76	0.93
11	0	0	82	15.46	1.11
12	0	0	78	17.75	1.44
13	0	0	76	18.07	1.33
14	0	0	79	19.38	1.3
15	0	0	76	17.57	1.2
16	0	0	83	17.02	1.26

Table 8: Variance analysis of uniformity of mortar.

Source of variation	Sum of squares	Degree of freedom	Mean square	Partial correlation	Specific value	Level of significance
X_1	0.8168	1	0.8168	0.8046	18.3604	0.0016
X_2	0.3332	1	0.3332	−0.6544	7.4889	0.021
$(X_1)^2$	0.1984	1	0.1984	−0.5554	4.4609	0.0608
$(X_2)^2$	0.0612	1	0.0612	−0.3479	1.3768	0.2678
X_1X_2	0.0025	1	0.0025	−0.0748	0.0562	0.8174
Regression	1.4121	5	0.2824	$F2 = 6.34863$		0.0273
Residue	0.4449	10	0.0445			
Lack of fit	0.2793	3	0.0931	$F1 = 3.93676$		0.0431
Error	0.1656	7	0.0237			
Sum	1.857	15				

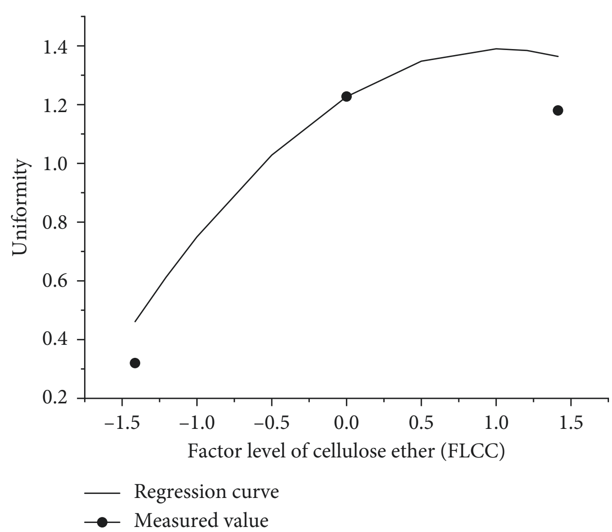

Figure 4: Influence of cellulose ether on uniformity when the substitution rate of rubber is 0.

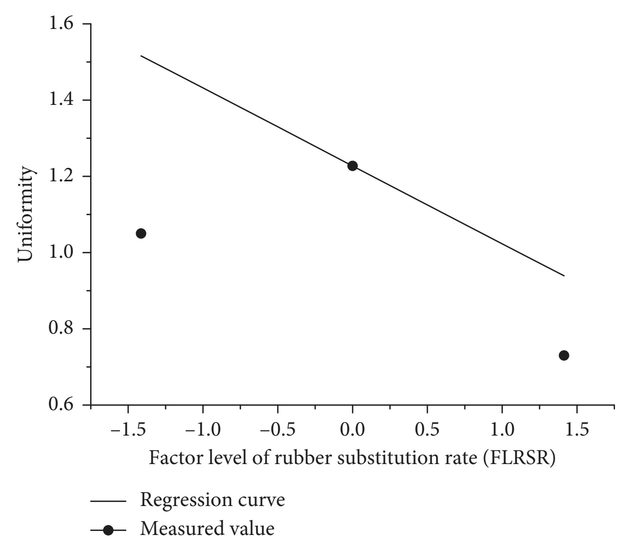

Figure 5: Influence of rubber on uniformity when the substitution rate of cellulose ether is 0.

The result of single-factor effect analysis of substitution rate of rubber is shown in Figure 5. With the increase of the substitution rate of rubber, the uniformity of rubber distribution shows a trend of linear reduction. It indicates that when the cellulose ether is at zero level, the increase of the substitution rate of rubber lowers the uniformity of rubber distribution.

The interaction effect of the substitution rate of rubber and mixing amount of cellulose ether on the uniformity of rubber distribution is shown in Figures 6 and 7. In Figure 7,

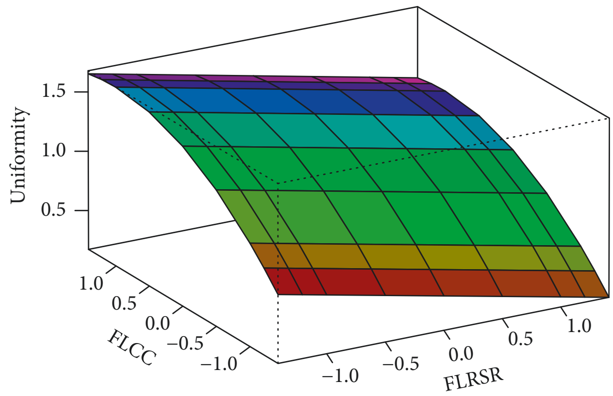

Figure 6: Schematic diagram of uniformity.

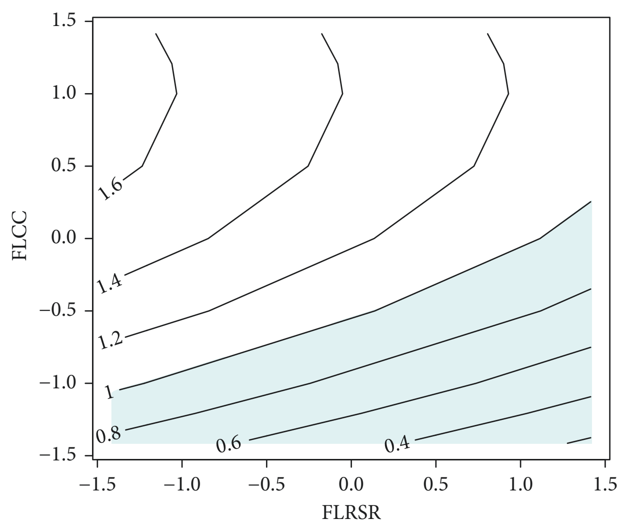

Figure 7: Contour map of uniformity (for the contour map of uniformity 1 as the boundary, the line on blue background in above figure represents the uniformity of rubber distribution that is smaller than 1, and the line on white background represents the uniformity of rubber distribution that is not smaller than 1).

we can find that the uniformity of rubber distribution presents a decreasing trend with the increase of substitute rate of rubber and presents an increasing trend with the increase of cellulose ether. The results show that the cellulose mixed into the rubber can significantly improve the uniformity of rubber distribution, and the mixing amount of cellulose required presents an increasing trend with the increase of substitute rate of rubber. The main reason is that the cellulose ether lowers the mobility of mortar and restrains the rubber particles from floating upward during vibration.

3.2. Analysis of Consistency Influence. Carry out variance analysis of influence factors on consistency, as shown in Table 9.

Get rid of the nonsignificant item in the regression equation whose P value is bigger than 0.1, and we can get the simplified regression equation: $Y = 78.25000 - 21.98160X_1 - 4.02665X_2$.

The curve of single-factor effect analysis of the mixing amount of cellulose regarding consistency is shown in Figure 8. With the increase of the mixing amount of cellulose ether, the consistency of mortar shows a trend of linear reduction, and the thickening effect of cellulose ether is significant, which accords with the research result [22] that cellulose ether has a good thickening effect on freshly mixed cement-based materials.

The curve of single-factor effect analysis of the substitution rate of rubber regarding consistency is shown in Figure 9. The consistency of mortar shows a trend of linear reduction with the increase of the substitution rate of rubber, and the descent of mobility is significant. The number of mesh of the rubber used in this study is 40, and the particle size is small, which accords with the conclusion [24] that rubber with small particle size can lower the mobility of cement mortar.

The interaction effect of the substitution rate of rubber and mixing amount of cellulose ether on the consistency of rubber distribution is shown in Figures 10 and 11. From Figure 11, we can find that the consistency of mortar shows a decreasing trend with the increase of the substitution rate of rubber and also shows a decreasing trend with the increase of cellulose ether. Meanwhile, the influence of the substitution rate of rubber on the consistency of mortar is larger than that of mixing amount of cellulose ether on the consistency of mortar.

3.3. Analysis of 28-Day Strength Influence. Carry out variance analysis of influence factor on 28 d strength, as shown in Table 10.

Get rid of the nonsignificant item in the regression equation whose P value is bigger than 0.1, and we can get the simplified regression equation: $Y = 17.13750 - 3.88368X_1 - 6.43565X_2\ 1.95688\ (X_1)^2 + 2.43000X_1X_2$.

The curve of single-factor effect of mixing amount of cellulose is shown in Figure 12. The 28 d strength presents a decreasing trend with the increase of mixing amount of cellulose. It indicates that when the substitution rate of rubber is at zero level, the increase of the mixing amount of cellulose ether lowers the 28 d strength of the mortar.

The curve of single-factor effect of the substitution rate of rubber is shown in Figure 13. The 28 d strength presents a trend of linear reduction with the increase of the substitution rate of rubber, which indicates that the rubber mixed into the mortar lowers the strength of the mortar. It also indicates that when the cellulose ether is at zero level, the increase of the substitution rate of rubber lowers the 28 d strength of the mortar.

The interaction effect of the substitution rate of rubber and mixing amount of cellulose ether on the 28 d strength of the mortar is shown in Figures 14 and 15. From Figure 15, we find that the 28 d strength of the mortar presents a decreasing trend with the increase of the substitution rate of rubber. When the mixing amount of rubber is zero, the 28 d strength of the mortar presents a decreasing trend with the increase of cellulose ether, which accords with the research [25]. When the substitution rate of rubber is 0.5, the 28 d strength of the mortar presents an increasing trend with the increase of cellulose ether. The author thinks it was resulting from the increase of uniformity of rubber distribution. At

Table 9: Variance analysis of consistency of mortar.

Source of variation	Sum of squares	Degree of freedom	Mean square	Partial correlation	F value	P value
X_1	3865.527	1	3865.527	−0.9793	233.9027	0.0001
X_2	129.7113	1	129.7113	−0.6631	7.8488	0.0187
$(X_1)^2$	45.125	1	45.125	0.4631	2.7305	0.1295
$(X_2)^2$	15.125	1	15.125	−0.2896	0.9152	0.3613
X_1X_2	0.25	1	0.25	0.0389	0.0151	0.9045
Regression	4055.738	5	811.1476	$F2 = 49.08247$		0.0002
Residue	165.2622	10	16.5262			
Lack of fit	89.7622	3	29.9207	$F1 = 2.77411$		0.0966
Error	75.5	7	10.7857			
Sum	4221	15				

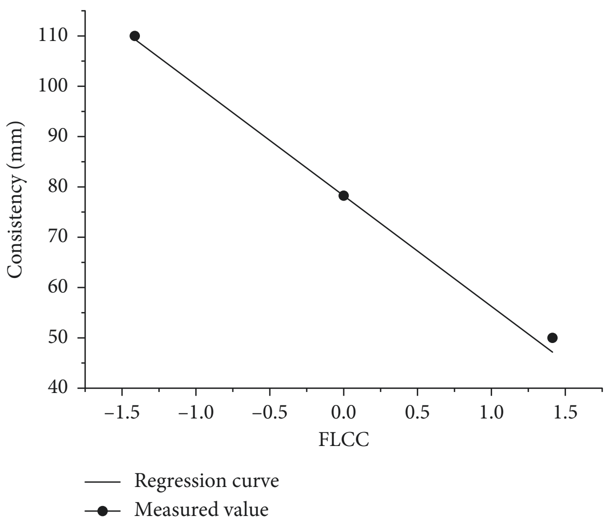

Figure 8: Influence of cellulose ether on consistency when the substitution rate of rubber is 0.

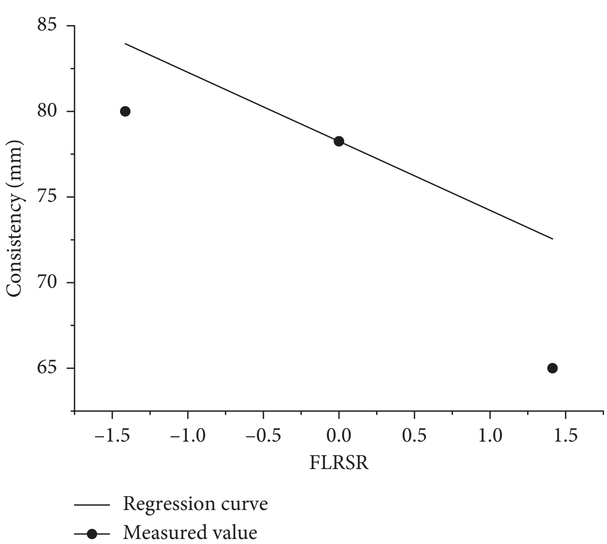

Figure 9: Influence of rubber on consistency when the level of cellulose ether is 0.

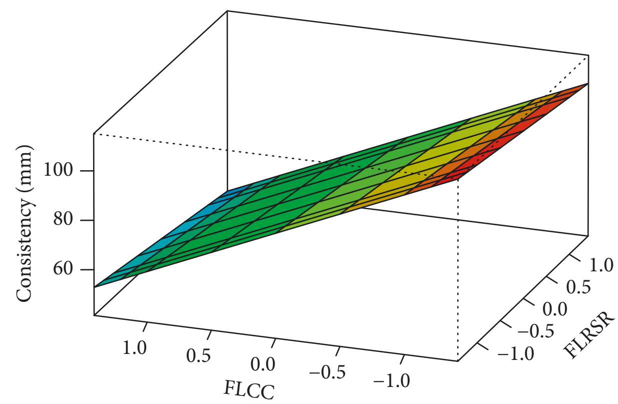

Figure 10: Schematic diagram of consistency.

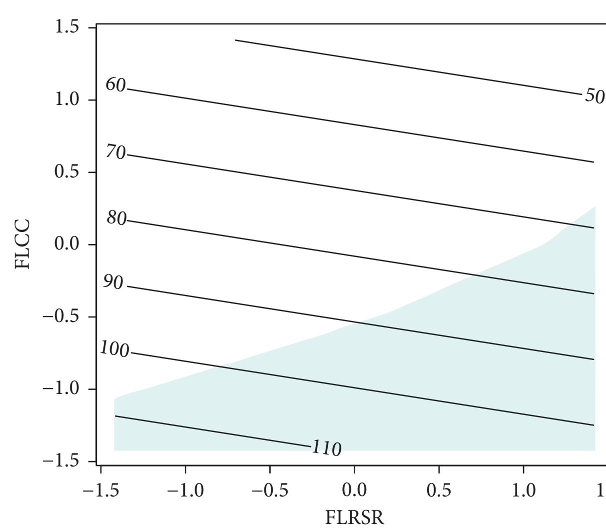

Figure 11: Contour map of consistency (for the contour map of uniformity 1 as the boundary, the line on blue background in above figure represents the consistency whose uniformity of rubber distribution is smaller than 1, and the line on white background represents the consistency whose uniformity of rubber distribution is not smaller than 1).

the same time, we can find the influence of the substitution rate of rubber on 28 d strength is larger than the influence of the mixing amount of cellulose ether on 28 d strength.

3.4. Discussion on the Floating of Rubber Particles in Mortar. Figure 16 is the cross section of K1 group, the substitution rate of rubber is 0.4268, and the mixing amount of cellulose ether is 4.6351 kg/m^3. The uniformity of rubber distribution

Table 10: Variance analysis of the 28 d strength of the mortar.

Source of variation	Sum of squares	Degree of freedom	Mean square	Partial correlation	Specific value	Level of significance
X_1	120.6639	1	120.6639	−0.8962	40.8106	0.0001
X_2	331.3408	1	331.3408	−0.9582	112.065	0.0001
$(X_1)^2$	30.6349	1	30.6349	0.7134	10.3612	0.0092
$(X_2)^2$	8.6424	1	8.6424	0.4756	2.923	0.1181
X_1X_2	23.6196	1	23.6196	0.6664	7.9885	0.018
Regression	514.9016	5	102.9803	$F2 = 34.82967$		0.0005
Residue	29.5668	10	2.9567			
Lack of fit	15.9437	3	5.3146	$F1 = 2.73079$		0.0998
Error	13.6232	7	1.9462			
Sum	544.4684	15				

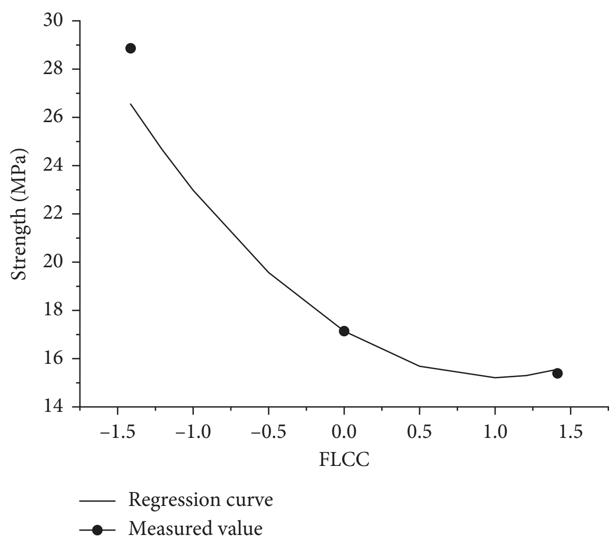

Figure 12: Influence of cellulose ether on 28 d strength when the substitution rate of rubber is 0.

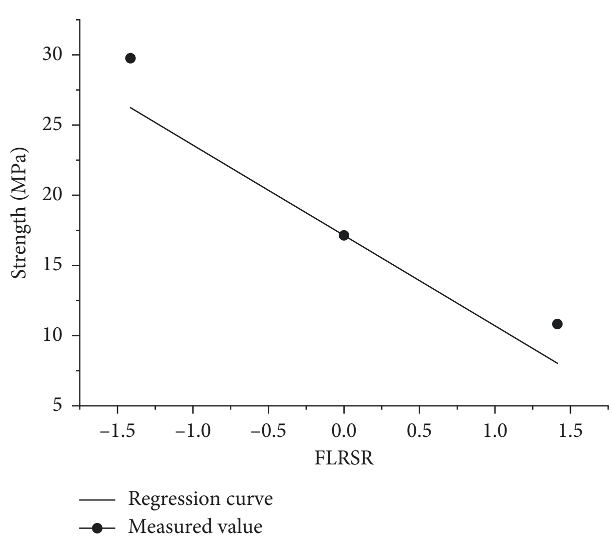

Figure 13: Influence of the substitution rate of rubber on 28 d strength when the mixing amount of cellulose ether is 0.

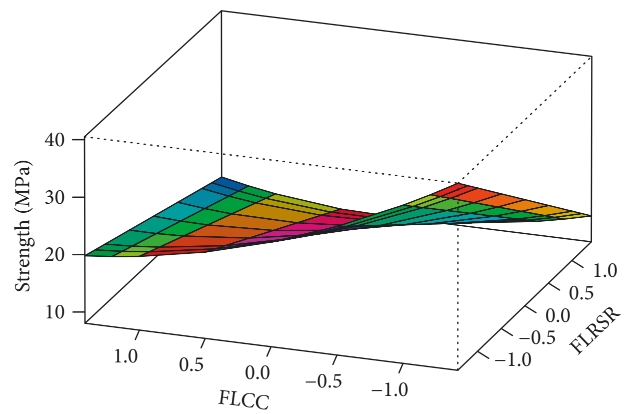

Figure 14: Schematic diagram of 28 d strength.

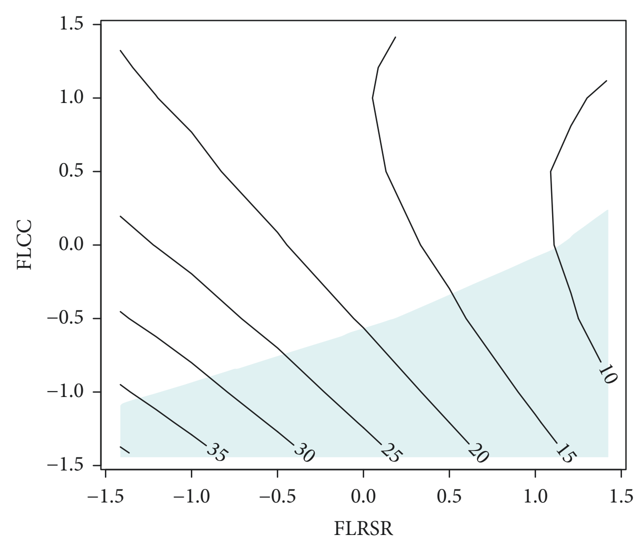

Figure 15: Contour map of 28 d strength (for the contour map of uniformity 1 as the boundary, the line on blue background represents the strength value when the uniformity of rubber distribution is less than 1, and the line on white background represents the strength value when the uniformity of rubber distribution is not less than 1).

is high, and the uniformity index is 1.16; Figure 17 is the cross section of K5 group, and the substitution rate of rubber 0.25. Since K5 group has not been mixed with cellulose ether, there exists a serious floating phenomenon of rubber particle, and the uniformity index is only 0.32. It indicates that the cellulose ether mixed into the rubber restrains the floating of cellulose ether.

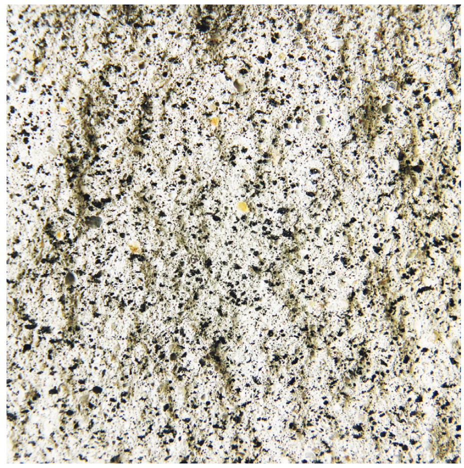

Figure 16: Profile map of K1 group with a uniformity of 1.16. The mixing amount of cellulose ether is 4.6351 kg and the substitution rate of rubber is 0.4268.

Figure 17: Profile map of K5 group with a uniformity of 0.32. The mixing amount of cellulose ether is 0 and the substitution rate of rubber is 0.25.

Table 11: Relationship between substitution rate of rubber and mixing amount of cellulose ether when rubber is uniformly distributed.

Level of substitution rate of rubber	−1.41	−1.21	−1.00	−0.50	0.00	0.50	1.00	1.21	1.41
Level of mixing amount of cellulose ether	−1.06	−0.99	−0.93	−0.75	−0.56	−0.34	−0.07	0.06	0.21
Substitution rate of rubber	0.00	0.04	0.07	0.16	0.25	0.34	0.43	0.46	0.50
Mixing amount of cellulose ether (kg)	0.68	0.80	0.94	1.27	1.64	2.07	2.58	2.83	3.13

When the uniformity of rubber distribution is no less than 1, we suppose that the rubber in the mortar is uniformly distributed, and there exists no floating of rubber. According to the regressive uniformity formula of rubber distribution, suppose the uniformity is equal to 1, and we can calculate the mixing amount of cellulose ether for different substitution rates of rubber, as shown in Table 11.

Carry out fitting based on the substitution rate of rubber and the mixing amount of cellulose ether, and we can get the formula of relation curve of different substitution rates of rubber and corresponding cellulose ether:

$Y = 4.78X + 0.58$, $R^2 = 0.9875$. According to this formula and different substitution rates of rubber, we can control the floating of rubber particles in mortar by mixing different amounts of cellulose ether into it.

4. Conclusion

This study carries out experiment by mixing cellulose ether into the concrete so as to improve the consistency of mixture and restrain rubber particles from floating upward. Besides, it adopts the method of quadratic orthogonal rotation combination, combining the index of uniformity of rubber distribution, and establishes the relationship between substitution rate of rubber and mixing amount of cellulose ether according to the uniformity index of rubber distribution. The main conclusions are as follows:

(1) Cellulose ether can significantly improve the consistency of mixture, lower the mobility of mortar, restrain rubber particles from floating upward, and increase the uniformity of rubber distribution.

(2) Based on the 28 d strength regression equation, when the mixing amount of rubber is zero, the 28 d strength of the mortar decreases with the increase of cellulose ether by 51.12%. When the substitution rate of rubber is 0.5, the 28 d strength of the mortar decreases with the increase of cellulose ether with a small proportion, by only 10.05%.

(3) Different mixing amounts of cellulose ether are required for different substitution rates of rubber. With the increase of the substitution rate of rubber, the mixing amount of cellulose ether required presents a trend of linear increase.

Data Availability

The experimental data used to support the findings of this study are available from the first author (sdaulj@163.com) and the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interests regarding the publication of this paper.

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