Effect of Surface Treatment of Waste Rubber Aggregate on Mortar Performance

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Abstract: The addition of waste rubber particles to cement mortar will reduce its strength, thus limiting the application of rubber cement mortar. The purpose of this study was to investigate the surface activation effect of different surface treatment methods on rubber particles of waste tires. In this experiment, water, NaOH and acetone were used to pretreat the surface of 40 mesh waste rubber particles. The contact Angle test was used to characterize the hydrophilicity of the pretreated rubber particles, and the SEM was used to analyze the micromorphology of the modified rubber particles. At the same time, the workability and mechanical properties of the modified cement mortar were also tested in this experiment to verify the practical application value of the pretreatment method in this experiment. The test shows that NaOH can effectively improve the surface hydrophilicity of rubber particles, improve the combination of rubber particles and cement mortar, and improve the compressive strength.

Keywords*: Rubber Particles; Cement Mortar; Surface Modification; Workability; Compression Strength*

I. INTRODUCTION

The workability and strength of rubberized concrete are critical indicators for evaluating its engineering applicability. Research has shown that the incorporation of rubber particles significantly affects the workability and strength of concrete, primarily depending on factors such as the morphology, particle size, surface treatment methods, and dosage of rubber particles.The addition of rubber particles has a dual impact on the workability of concrete. On the one hand, the hydrophobic nature of rubber particles and the air carried on their surfaces reduce the fluidity and uniformity of concrete, leading to a decline in workability. On the other hand, the elastic properties of rubber particles can improve the toughness, ductility, and damping capacity of concrete, enabling it to exhibit better energy absorption under dynamic loads.Studies have shown that the workability of rubberized concrete is closely related to its mix design. For example, when rubber particles completely replace fine aggregates, the fluidity of concrete is significantly reduced. However, appropriate surface treatments (such as NaOH solution immersion or water washing) can improve the interfacial bonding between rubber and the cement matrix, thereby partially restoring its workability[1-3]. Additionally, the incorporation of mineral admixtures such as silica fume (SF) has been proven effective in reducing the porosity of rubberized concrete, enhancing its compactness and fluidity[4,5].The strength of rubberized concrete is one of the main limiting factors in its application. Research has found that the incorporation of rubber particles significantly reduces the compressive strength and splitting tensile strength of concrete. For instance, when waste rubber completely replaces fine aggregates, the compressive strength and splitting tensile strength decrease by 65% and 50%, respectively. This reduction in strength is primarily attributed to the poor interfacial bonding between rubber and the cement matrix, as well as the pores and microcracks introduced by rubber particles in the concrete.However, through reasonable surface pretreatment and chemical modification, the strength performance of rubberized concrete can be significantly improved. For example, F. Pelisser, N. Zavariseet al.[6] achieved only a 14% reduction in compressive strength compared to conventional concrete by using NaOH solution treatment and adding silica fume. Youssf et al. and Rostami et al.[7-,8]improved the compressive strength of rubberized concrete by 15% and 16%, respectively, through water immersion and simple water washing of rubber particles. Furthermore, Kashani et al.[9] found that H_2SO_4 treatment increased the compressive strength of acid-treated rubberized concrete by approximately 56%.Chinese scholars have also made significant progress in the study of rubberized concrete strength. In summary, the workability and strength of rubberized concrete are influenced by various factors. Through reasonable surface pretreatment, chemical modification, and mix design optimization, its performance can be significantly improved, providing a theoretical basis and technical support for its application in engineering. Future research should further explore the interfacial modification mechanisms between rubber particles and the cement matrix, as well as the potential of novel additives and pretreatment methods in enhancing the performance of rubberized concrete.

II. EXPERIMENTAL PROCEDURES

A. Raw materials and mix ratio

The raw materials utilised in this study for the production of rubber mortar encompass cement, natural river sand, tap water, and rubber powder. The cement employed in this study is a PO•42.5 variety, manufactured by Jiaozuo Qianye Cement Co., Ltd. The fineness modulus of the natural river sand utilised is 2.93, and its apparent density is 2850 kg/m3. The rubber powder was obtained by crushing the treads of waste tyres. The particle size of the rubber powder is 40 mesh (approximately 0.425 mm), its apparent density is 1042 kg/m³, and its acetone extract content is 6.53%.

In this experiment, a water-to-cement ratio of 0.5 and a cement-to-sand ratio of 1:3 were utilised for the mixture. Concurrently, rubber powder was incorporated into the mixture at 0%, 0.5%, 1.0%, 1.5%, 2.0%, and 2.5% of the mass of the fine aggregate (natural river sand). These are denoted by CR0, CR0.5, CR1.0, CR1.5, CR2.0, and CR2.5, respectively. The mix proportions of the rubber mortar are shown in Table 1.

Table 1: Rubber mortarmix proportion

NO.	Water/g	Sand/g	Cement/g	Rubber/g
1	225	1350	450	0
2	225	1350	450	7.65
3	225	1350	450	15.3
4	225	1350	450	22.98
5	225	1350	450	30.6
6	225	1350	450	38.25

B. Surface pretreatment

The waste rubber particles are placed in the tray, a small amount of tap water is added to rub, so that the rubber particles are completely wet by water, and then the tray is put into the oven, and the rubber particles are dried out for use.

The waste rubber particles are placed in the tray, and the NaOH solution with a mass fraction of 5% is added to the tray for a small number of times for kneading, so that the rubber particles are completely wet by NaOH solution. After that, the tray is put into the oven, and the rubber particles are dried and taken out for use.

The waste rubber particles are placed in the tray, and a small amount of acetone solution with a mass fraction of 5% is added for kneading, so that the rubber particles are completely wet by the acetone solution. Then the tray is put into the oven, and the rubber particles are dried and taken out for use.

C. Forming and Curing

Waste rubber particles instead of part of the fine aggregate added to the cement, sand, mechanical mixing to uniform, and then add water and water reducing agent continue to stir, after mixing uniform measurement of fluidity and bulk density, and then the uniform mortar loaded into 40 mm×40 mm×160 mm steel mold, on the shaking table vibration compaction molding.

It was placed in the standard curing room for one day, and the mold was removed after full molding, and then wrapped with plastic wrap and continued to be placed in the curing room for curing. Then the flexure and compressive strength of 3, 7, and 28 days were measured respectively.

D. Test method

The contact Angle of the surface treated waste rubber powder was obtained by the contact Angle measuring instrument. The tests were performed at room temperature of 25 ° C. The contact Angle device was used to test the untreated group and the rubber particles treated with water, NaOH, and acetone, respectively. Each type of sample was determined more than four times, and then their average value was calculated.

When the rubber cement mortar is stirred evenly, the fluidity of the cement mortar is tested by the mechanical vibration tester, and the bulk density is tested by the capacity barrel.

The untreated rubber and the rubber with surface treatment (water pretreatment, NaOH pretreatment, acetone pretreatment) were added to the cement base, and the samples were formed. The compressive and flexural properties of these samples were tested to verify the influence of the pretreatment method on the waste rubber particles. The size of the sample used in the test was 40 mm×40 mm×160 mm. The compression and flexural strength of the sample for 3 days, 7 days and 28 days were measured respectively, and the flexural compression ratio was calculated.

Scanning electron microscope (SEM) was used to observe the micromorphology of waste rubber particles before and after modification. Four kinds of rubber powders were tested. The magnification for this test was 5000. Before the test, the rubber particles were treated with gold spray.

III. RESULT AND DISCUSSION

A. Contact angle

Fig.1 is a bar chart of the rubber contact Angle size after pretreatment, and Fig.2 is a schematic diagram of the rubber particle contact Angle. It can be seen from the figure that the contact Angle on the surface of the waste rubber particles is reduced after pretreatment with different solvents. The contact Angle of the untreated rubber particles was 104.6. Compared with the untreated group, the contact angles of the water pretreatment group, the NaOH pretreatment group and the acetone pretreatment group were reduced by 13.3%, 28.95% and 16.03%, respectively. After comparison, we found that the contact Angle of the rubber pretreated with NaOH solution changed the most, and the hydrophilic property was the best, followed by the acetone solution and water pretreatment. For untreated rubber, its surface is attached to oil and small impurities, so its hydrophilicity is the worst; Water and NaOH can clean the oil on the surface of rubber particles, but NaOH, as an alkaline solution, has a stronger ability to remove oil. The oil on the surface of rubber particles is mostly aromatic oil, and acetone as an organic solvent can be well mismixed with oil, but because it is not cleaned in time, there are still some oil on the surface of rubber particles.

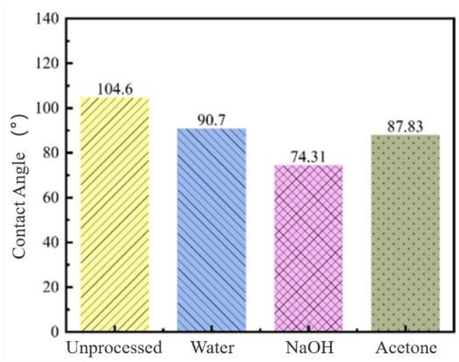
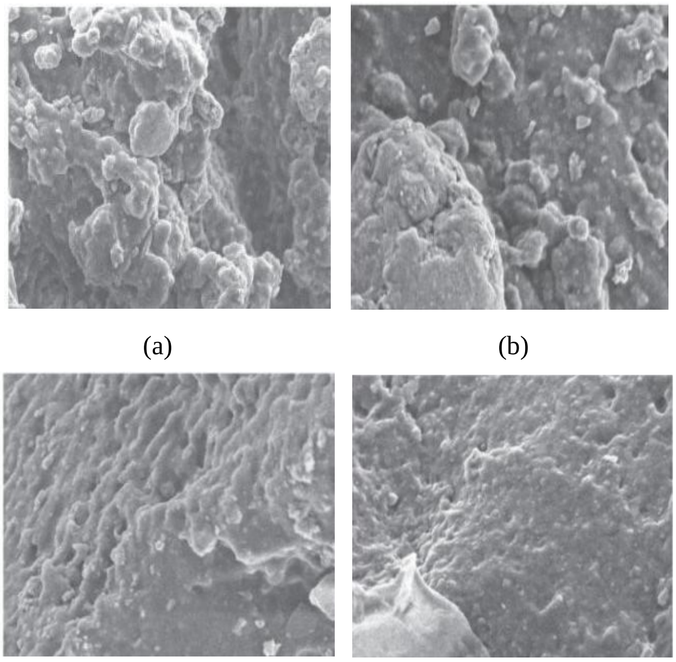


Fig.1 Contact angle of rubber particles after pre-treatment

B. Micromorphology of pretreated rubber particles

Fig.2 shows the SEM images of the surface of the rubber particles pretreated with water, NaOH and acetone solutions as well as the untreated ones. Observing the SEM images, we can see that the surface of the rubber particles pretreated with water still contains more impurities. These impurities are of different sizes, but the diameter of the impurities is small. The surface protrusion of rubber particles pretreated with NaOH solution is reduced and smoother. This is because NaOH reacts with the substances on the rubber surface, thereby removing the hydrophobic substances on the rubber surface and improving the hydrophicity of the rubber particle surface. The surface impurities of rubber particles pretreated with acetone solution are reduced more than that of water pretreatment, and less than that of NaOH pretreatment. The reason is that NaOH has strong alkalinity and can interact with more hydrophobic substances. In general, the microscopic improvement of the colloidal surface by NaOH pretreatment was more obvious[10].



(a) (b)

(c) (d)

Fig.2 SEM images of rubber particles after preprocessing: (a) Untreated; (b) Water; (c) NaOH; (d) Acetone

C. Degree of flow

Fig.3 shows the graph of the influence of different surface modified rubber particles on the fluidity of mortar. It can be seen from the figure that after adding rubber particles, the fluidity of cement mortar decreases, which is due to the fact that the incorporation of rubber particles reduces the apparent density of mortar, and the friction between rubber particles is large, which affects the movement of aggregate and reduces the fluidity of mortar. Thus, the greater the content of rubber particles, the smaller the fluidity of mortar. When adding the same content of rubber particles, the fluidity is: untreated>water pretreatment > acetone pretreatment > NaOH pretreatment. The reason is that NaOH solution reacts with zinc stearate in rubber to generate $Na(C_{17}H_{35}COO)_2Zn$, which makes the interface smoother and increases the contact area between the interface colloids[11]. Water pretreatment only removes impurities on the surface of rubber particles through physical action, but relatively speaking, it also increases the contact area of rubber particles.

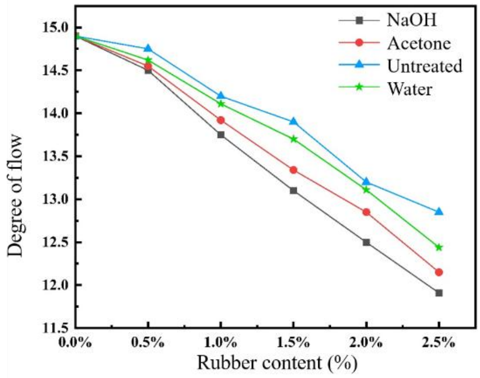


Fig.3 Fluidity of mortar after adding different modified rubber

D. Compression strength

Fig.4 shows the compressive strength of the sample after 28 days of curing. The results show that when the curing age is 28 days, compared with the previous sample strength, the strength of 28 days is higher, within 40±4 MPa. After NaOH treatment, the effect intensity was the largest, followed by acetone, water and other treatments, and the effect intensity was the smallest after no treatment.

With the continuous addition of rubber particles, the compressive strength of the sample decreases. The interface between rubber particles and cement matrix is loosely combined, there are obvious pores at the interface, and the bonding is poor, so it cannot be well combined. With the addition of more rubber particles, the network structure formed by cement hydration is greatly damaged, and the effect of rubber particles on reducing the strength of cement mortar is greater than that of gap filling, which leads to a large reduction in compressive and flexuous strength.

When the rubber content is the same, the strength of the four groups of samples is roughly as follows: NaOH treatment > acetone treatment > water treatment >Untreated. Compared with untreated samples, NaOH pretreatment improved the compressive strength of the samples more than acetone pretreatment and water pretreatment.

These results can be explained by the microscopic morphological changes of rubber particles. The NaOH solution reacts with the impurities on the surface of the rubber particles, which increases the contact area between the rubber particles and the cement, and reduces the gap between the rubber and the cement base, so as to improve the adhesion and improve the compressive strength of the sample.[1,2,11]Compared with NaOH, the removal effect of acetone on rubber surface impurities is not very obvious, which can also be confirmed by the contact Angle test and SEM image.

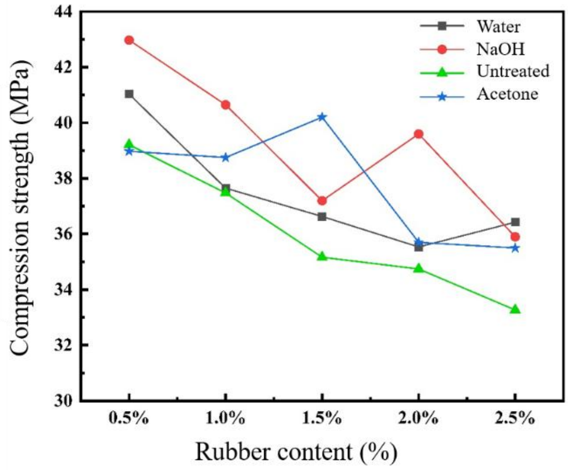


Fig.4 Compressive strength of specimen cured for 28 days

CONCLUSIONS

In this experiment, three solutions—water, NaOH, and acetone—were used to treat rubber particles, and the effects of pretreatment methods on the surface of rubber particles were investigated. The contact angle, SEM, fluidity of rubberized mortar, and compressive strength were tested for the pretreated rubber particles. The following conclusions were drawn:

Tests on the contact angle of treated rubber particles revealed that pretreatment can reduce the contact angle, improving the hydrophilicity and surface activity of the rubber particles. Compared to untreated rubber particles, the contact angle of rubber particles pretreated with NaOH solution showed a significant decrease. Although the contact angles of particles pretreated with acetone and water also decreased, they remained higher than those of the NaOH-treated group. This indicates that NaOH is more suitable for the surface pretreatment of waste rubber particles.

The incorporation of rubber particles affects the fluidity and compressive strength of mortar. As the rubber content increases, both the fluidity and compressive strength decrease. In comparison, the modification effect of NaOH is the most effective.

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