Experimental analysis on the effects of artificial marble waste powder on concrete performance

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ABSTRACT. *This paper blends and adds artificial marble waste powder to concrete, aiming to disclose the effects of the powder on the physical and mechanical properties of concrete. The slump and other working properties of the fresh concrete were tested, and several mechanical parameters of the hardened concrete were measured, including cube compressive strength, flexural strength, elastic modulus and splitting tensile strength. Through the analysis of the test results and measured data, the following conclusions were put forward: Both blending and addition of artificial marble waste powder can improve the cohesiveness and bleeding of concrete. The blending is an effective way to increase the slump of concrete, while the addition suppresses the slump. During the addition, the strength indices of the concrete were all on the rise; the indices reached the maximum at the dosage of 10~15%, were comparable to those of the control group at the dosage of 20%, and plunged rapidly when the dosage surpassed 25%. The splitting tensile strength and the cube compressive strength has a power function relationship with the correlation coefficient of 0.845; the flexural strength and the cube compressive strength has a linear relationship with the correlation coefficient of 0.995; the elastic modulus and the cube compressive strength has a power function relationship with the correlation coefficient of 0.738. Finally, it is recommended to add 20% of artificial marble waste powder into concrete. The research findings lay the basis for the application of artificial marble waste powder in concrete and provide a new mineral admixture for the concrete industry.*

RÉSUMÉ. *Cet article mélange et ajoute de la poudre de déchets de marbre artificiel au béton dans le but de révéler les effets de la poudre sur les propriétés physiques et mécaniques du béton. L'affaissement et les autres propriétés de fonction du béton frais ont été testés et plusieurs paramètres mécaniques du béton durci ont été mesurés, tels que la résistance à la compression du cube, la résistance à la flexion, la résistance du module d'élasticité et de la rupture par traction. L'analyse des résultats de test et des données mesurées a permis de tirer les conclusions suivantes: le mélange et l'ajout de poudre de déchets de marbre artificiel peuvent améliorer la cohésion et le ressuage du béton. Le ressuage est un moyen efficace d'augmenter l'affaissement du béton, tandis que l'addition supprime l'affaissement. Au cours* *de l'addition, les indices de résistance du béton ont tous augmenté. Les indices ont atteint le maximum à la dose de 10 à 15%, étaient comparables à ceux du groupe témoin à la dose de 20% et ont chuté rapidement lorsque la dose a dépassé 25%. La résistance à la rupture par traction et la résistance à la compression du cube ont une relation fonctionnelle de puissance avec le coefficient de corrélation de 0,845; la résistance à la flexion et la résistance à la compression du cube ont une relation linéaire avec le coefficient de corrélation de 0,995; la résistance du module d'élasticité et de la compression du cube ont une relation fonctionnelle de puissance avec le coefficient de corrélation de 0,738. Enfin, il est recommandé d'ajouter 20% de poudre de déchets de marbre artificiel dans le béton. Les résultats de la recherche jettent les bases de l'application de la poudre de déchets de marbre artificiel dans le béton et fournissent un nouveau mélange de minéraux pour l'industrie du béton.*

KEYWORDS: *artificial marble waste powder, concrete, water consumption, working performance, mechanical properties.*

MOTS-CLÉS: *poudre de déchets de marbre artificiel, béton, consommation d'eau, performance de fonctionnement, propriétés mécaniques.*

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1. Introduction

Located in Southwest China's Guangxi Zhuang Autonomous Region, Hezhou Municipality is one of the main producing areas of marble in China. The proven reserves of white marble in Hezhou amount to 2.6 billion m^3, equivalent to around 300 years at current production levels. Taking white marble as the raw material, the calcium carbonate ($CaCO_3$) industry in Hezhou has an output value of hundreds of billions in RMB, making it a key industry in Guangxi. With the yearly increase in marble mining and consumption, a huge amount of solid wastes (e.g. waste residue, waste powder and waste slurry) have emerged during mining, transport, cutting and grinding (Mashaly *et al.*, 2016). About 70% of the raw marble is lost in these processes (Hebhoub *et al.*, 2011), causing huge economic losses to the industry and severe pollution to the environment. Currently, the waste residue and waste powder generated in marble mining, cutting and grinding can be re-ground into marble powder of different fineness, and mixed with unsaturated resin, curing agent and accelerant, creating artificial marble blocks. However, waste powder is still produced when the blocks are cut into finished products. In 2016, there are 44 artificial marble production lines in Hezhou, producing over 800,000 tons of solid wastes. With components like resin, the waste powder of artificial marble cannot be utilized in other industries but be disposed locally, which takes up a wide area of land. What is worse, the artificial marble powder will float in the air, enter into water or deposit on the ground, leading to serious pollution to the soil, the air and the water environment, not to mention its health hazards. The large amount of waste powder has a serious impact on the environment and hinders the development of the local marble industry. Against this backdrop, the reuse of marble solid wastes will bring unmeasurable environmental and economic benefits (Rana *et al.*, 2015). So far, the solid wastes of natural marble have been adopted as a mineral admixture for cement, a coarse or fine aggregate and a mineral admixture for concrete, and a soil conditioner. However, there is no report on the reuse of artificial marble waste powder. Thus, it is imperative to explore the resource utilization of artificial marble waste powder.

The past decade has seen a growing awareness of the environmental pollution of marble solid wastes across the world. More and more scholars have attempted to apply these wastes in concrete engineering. For instance, References (Topcu *et al.*, 2009; Corinaldesi *et al.*, 2010) mix marble powder and slurry into concrete as a mineral admixture to examine its effect on concrete performance, revealing that marble powder can improve the performance of cement-based cementitious materials. Through chemical analysis and particle size analysis, Reference (Bacarji *et al.*, 2013) discovers that marble powder, as an inactive material, only serves as a filler in concrete. However, Reference (Ronglin, 2016) holds that marble powder can acquire hydration activity in the late stage of hydration. References (Dhoka, 2013) suggest that the $CaCO_3$ in marble powder can accelerate the early hydration speed of C_3S in cement, prevent Aft from transforming into AFm, and combine with aluminate minerals to form a small amount of single-carbon hydrated calcium aluminate(C_3 $A{\cdot}CaCO_3{\cdot}11H_2O$); therefore, adding a proper amount of marble powder (8%~10%) can improve the mechanical properties of cement paste and increase the water demand of cement. References (Demirel, 2010) conclude that the filling effect of marble powder reduces the porosity and enhances the cohesion of concrete. Reference (Bonavetti & Irassar, 1994) points out that the concrete porosity increases with the growth in the dosage of marble fragments.

Most studies suggest that the concrete strength can be increased by adding a certain proportion of marble powder (Binici *et al.*, 2007). However, References (Rodrigues *et al.*, 2015; Ergun, 2011) hold that mechanical properties of concrete may be reduced as marble powder replaces cement, and the attenuation of concrete strength can be compensated by using water reductant. Reference (Alyanac & Aydin, 2015) discovers that the compressive strength of the concrete after the cement is replaced with 5% marble powder is improved through the addition of water reductant. Reference (Singh *et al.*, 2016) finds that the concrete strength can satisfy the standard with the addition of over 40% marble powder. Nevertheless, when the dosage of marble powder surpasses 50%, the working performance of the concrete is improved at the cost of compressive strength and splitting tensile strength. Reference (Singh *et al.*, 2017; Singh *et al.*, 2017; Ulubeylia & Artir, 2015) put the optimal replacement ratio of marble powder at 15%. In addition, the marble powder has been found to improve the durability of concrete (Ulubeylia *et al.*, 2016), especially water absorbability, permeability, resistance to Cl^- penetration and resistance to sulfate attack.

These studies provide an important reference for the application of marble waste powder in concrete. However, there are many disagreements on the conclusions, which may have arisen from the varied dosages and mixing methods as well as the difference in composition and fineness between marble powder produced in different regions. Some scholars believe that the addition of marble powder can increase the concrete strength to a certain degree, while some have found the negative correlation between concrete strength and marble powder dosage. Some scholars believe that marble powder has hydration activity, while some do not agree.

Some scholars believe that marble powder can reduce the concrete porosity, while some hold the opposite view. In addition, all these studies target the solid wastes from natural marble, failing to explore those from artificial marble containing organic impurities like resin. To sum up, there is no systematic research into the applicability of artificial marble waste powder in concrete engineering.

To make up for this gap, this paper probes into the effects of artificial marble waste powder, which contains organic impurities, on the physical and mechanical properties of concrete, with the aim to apply artificial marble waste powder in concrete industry, turning the waste into treasure, and to eliminate the negative impact of the powder on the environment. The research findings lay the basis for the application of artificial marble waste powder in concrete and provide a new mineral admixture for the concrete industry.

2. Methodology

2.1. Raw materials

The cement for our test, denoted as C, was Runfeng (rotary kiln) P.O 42.5 grade cement produced by China Resources (Fuchuan) Cement Plant. The chemical composition, physical-mechanical properties, fineness parameters (e.g. particle size) and particle size distribution of the cement are presented in Table 1, Table 2, Table 3 and Figure 1, respectively.

The artificial marble waste powder for our test, denoted as MP, was obtained from Guangxi Lisheng Stone Co., Ltd. The chemical composition, fineness parameters (e.g. particle size), particle size distribution and appearance of the artificial marble waste powder are presented in Table 1, Table 3, Figure 1 and Figure 2, respectively.

Table 1. Chemical composition of cement and artificial marble waste powder

	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3	K_2O	Na_2O	LOI	other
C	21.80	4.60	2.40	0.10	64.47	1.40	1.99	0.60	0.30	1.90	0.44
MP	0.05	13.85	34.13	0.20	0.68	4.00	0.08	0.37	0.05	46.65	5.43

Table 2. Physical-mechanical properties of cement

Requirement of normal consistency (%)	Setting times (min)		Flexural strength (MPa)		Compressive strength (MPa)	
	Initial	Final	3d	28d	3d	28d
27.6	158	208	5.4	7.4	26.3	43.3

Table 3. Particle size distribution and basic properties of cement and artificial marble waste powder

	D(4,3) (μm)	D(3,2) (μm)	Particle size (μm)				Specific gravity (g/cm^3)	Specific surface area (m^2/kg)
			D10	D50	D90	D97		
C	18.28	2.86	0.93	11.13	33.86	46.18	3.11	327
MP	6.42	2.10	0.86	3.50	17.42	24.28	2.61	772

The water for our test is drinkable tap water.

Fine aggregates for our test are natural river sands from Wuzhou, Guangxi while the coarse aggregates for our test are continuously graded fragments of natural limestone with a maximum particle size of 25 mm.

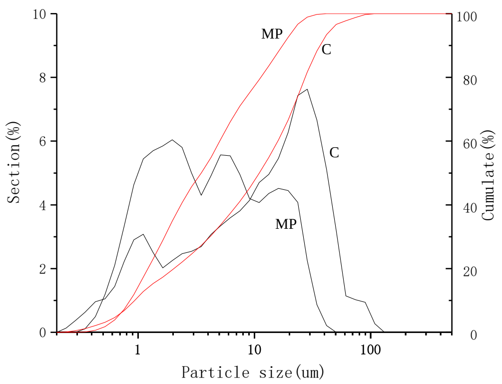
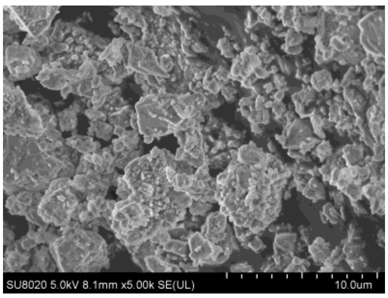
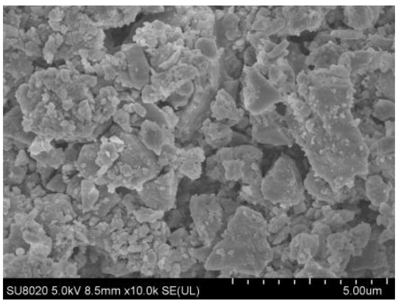


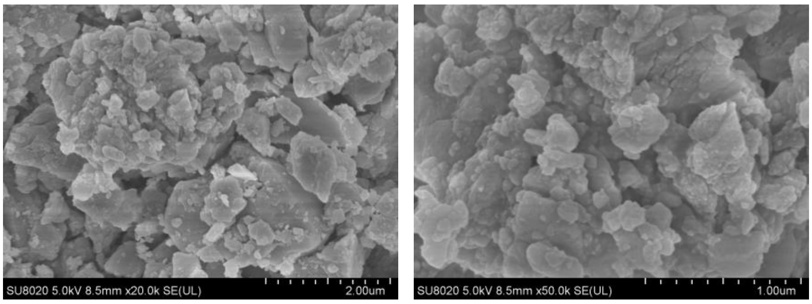
Figure 1. Single and cumulative particle size distribution curves of artificial marble waste powder and cement particles



(a) × 5,000 times



(b) × 10,000 times



(c) × 20,000 times *(d) × 50,000 times*

Figure 2. Scanning electron microscopy (SEM)image of artificial marble waste powder: Lamellar structure

2.2. Mix ratios

Table 4. Concrete mix ratios

Mixing method	No	Marble powder Dosage (%)	Water (kg)	Cement (kg)	Marble powder (kg)	Fine aggregates (kg)	Coarse aggregate (kg)
--	C0	0	190.0	345.47	0.00	651.93	1212.6
Blending	MPN-1	5	190.0	328.20	17.27	651.93	1212.6
	MPN-2	10	190.0	310.92	34.55	651.93	1212.6
	MPN-3	15	190.0	293.65	51.82	651.93	1212.6
	MPN-4	20	190.0	276.38	69.09	651.93	1212.6
	MPN-5	25	190.0	259.10	86.37	651.93	1212.6
Addition	MPW-1	5	190.0	345.47	17.27	651.93	1212.6
	MPW-2	10	190.0	345.47	34.55	651.93	1212.6
	MPW-3	15	190.0	345.47	51.82	651.93	1212.6
	MPW-4	20	190.0	345.47	69.09	651.93	1212.6
	MPW-5	25	190.0	345.47	86.37	651.93	1212.6
	MPW-6	30	190.0	345.47	103.64	651.93	1212.6

A total of 12 tests were designed with the concrete strength of C30. One of these tests, denoted as C0, serves as the control test, because 0% artificial marble waste powder was added into the concrete. Five of these tests are denoted as MPN, for artificial marble waste powder was blended into the concrete specimens by the mass percent of cement, respectively 5%, 10%, 15%, 20% and 25%, replacing the cement. Six of these tests are denoted as MPW, for artificial marble waste powder was added onto the concrete specimens by the mass percent of cement, respectively 5%, 10%, 15%, 20%, 25%and 30%, without replacing any component. The specific mix ratios are listed in Table 4 above.

2.3. Methods

(1) Working performance of fresh concrete

To evaluate the working performance of fresh concrete, the slump was measured and the bleeding and cohesiveness were observed according to the *Standard for Test Method of Performance on Ordinary Fresh Concrete* (GB/T 50080-2002).

(2) The basic mechanical properties of concrete

The basic mechanical properties of concrete, such as cube compressive strength, splitting tensile strength, flexural strength and elastic modulus, were tested according to the *Standard for Test Method of Mechanical Properties on Ordinary Concrete* (GB/T 50081-2002).

3. Test results and discussion

3.1. Working performance of fresh concrete

Table 5 displays the test results on the slump, cohesiveness and bleeding of fresh concrete. The relationship between slump and MP dosage is illustrated in Figure 3.

As shown in Table 5 and Figure 3, the concrete slump increased with the MP dosage in MPN tests. The slump increase stood at 0, 10, 15, 25 and 40mm when the MP dosage was 5%, 10%, 15%, 20% and 25%, respectively. By contrast, the concrete slump declined with the growth in the MP dosage in MPW tests. The slump decrement reached 30, 55, 70, 80, 85and 90mm when the MP dosage was 5%, 10%, 15%, 20%, 25% and 30%, respectively. After the blending of the MP, the concrete cohesiveness changed from poor to moderate and general, and the concrete bleeding improved significantly from slight bleeding to no bleeding; after the addition of the MP, the concrete cohesiveness changed from poor to general and good, and the concrete bleeding improved significantly from slight bleeding to no bleeding.

The positive correlation between the slump and the MP dosage in MPN tests can be explained as follows. The hydration reaction started once the cement particles were in contact with water, turning the free water in the concrete mixture partially into adsorbed water and compound water. The marble powder, generally considered as inactive, only needs to be wetted and wrapped by water in the concrete system. Hence, the artificial marble waste powder requires fewer water than cement. In the

MPN tests, the water consumption was kept constant. In this case, the amount of cement decreased with the increase of artificial marble waste powder, leading to a proportional decline in the water demand of cement. Whereas the growing artificial marble waste powder consumes fewer water than the decreasing cement, the chemical water demand of the entire system exhibited a decline, causing a relative increase of free water in the mixture. In addition, the artificial marble waste powder has a large specific surface area as well as concentrated and small particle size, compared with cement. Thus, the powder mainly acts as a filler in the concrete mixture, reducing the porosity of the concrete. As the concrete became more compact, there was fewer space for free water in the concrete, and relatively more water content in the mixture. The flowability of the mixture was thus improved, pushing up the concrete slump. Furthermore, the concrete cohesiveness was enhanced because the artificial marble waste powder filling between cement particles existed in the form of flakes, which hinders the flow of cement slurry. After all, flake particles are less flowable than spherical cement particles.

Table 5. Test results on the working performance of fresh concrete

Mixing method	No	Marble powder Dosage (%)	Slump (mm)	Cohesiveness	Segregation
--	C0	0	145	Slightly worse	Slight
Blending	MPN-1	5	145	commonly	absence
	MPN-2	10	155	moderate	absence
	MPN-3	15	160	good	absence
	MPN-4	20	170	moderate	absence
	MPN-5	25	185	moderate	absence
Addition	MPW-1	5	115	commonly	Slight
	MPW-2	10	90	good	absence
	MPW-3	15	75	good	absence
	MPW-4	20	65	good	absence
	MPW-5	25	60	good	absence
	MPW-6	30	50	good	absence

The negative correlation between the slump and the MP dosage in MPW tests is attributable to the following reasons. In MPW tests, the water consumption and cement amount were kept unchanged, while the amount of artificial marble waste powder was on the rise. Hence, the water demand of the cement remains constant. Since the added powder needs to be wetted and wrapped by the water in the system, the greater the powder dosage, the fewer the free water and the smaller the slump.

Moreover, the flake-shaped powder penetrated into and filled up the gaps between the spherical cement particles, which impedes the rolling of the spherical beads of the cement slurry. Thus, the concrete becomes less flowable and less likely to slump. Furthermore, the concrete cohesiveness and bleeding were improved as the flake-shaped artificial marble waste powder filled between cement particles and hindered the flow of cement slurry, as they are less flowable than spherical cement particles.

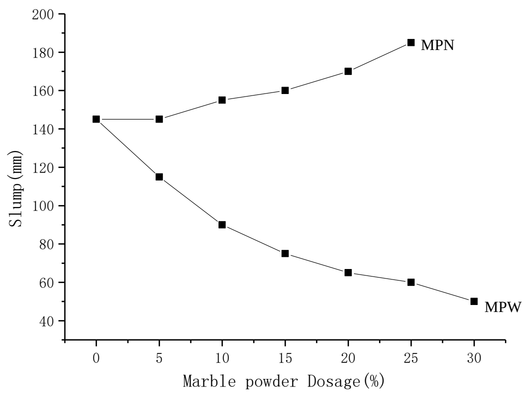


Figure 3. Relationship between slump of fresh concrete and MP dosage

Meanwhile, the unsaturated resin in the artificial marble waste powder is a linear polymer compound with multifunctional groups. There are a polyester bond and an unsaturated double bond in the main chain of the skeleton, as well as hydroxyl groups and carboxyl groups at both ends of the macromolecular chain. The carboxyl group at the end of the polyester chain can react with alkaline earth metal oxides like CaO and MgO or with hydroxides like $Ca(OH)_2$. The reaction will expand the molecular chain of the unsaturated polyester, making it possible to form a complex. In essence, the curing of unsaturated resin is a cross-linking polymerization reaction of an unsaturated double bond in the molecular chain with a double bond of a crosslinking monomer, which turns the linear long-chain molecules into a three-way crosslinked insoluble and infusible 3D grid structure. The 3D grid-like resin chain will coat and solidify the marble powder in a uniform manner, so that the powder can easily aggregate into balls. After being added onto the concrete, the powder balls are very likely to aggregate with other components in the concrete, making the concrete more compact and the mixture less flowable.

3.2. Mechanical properties of hardened concrete

The test results on the cube compressive strength, flexural strength and other mechanical properties of concrete are recorded in Table 6. Based on these results, the relationships between the mechanical indices were plotted as Figures 4 and 5, where the MPN dosages are listed as negatives to highlight the different impacts of blending and addition on concrete mechanics.

Table 6. Test results on concrete mechanical properties

Mixing method	No	Marble powder Dosage (%)	f_{cu} (Mpa)				f_{ts} (Mpa)	f_{tf} (Mpa)	E (10^4Mpa)
			3d	7d	14d	28d			
--	C0	0	23.8	29.8	33.1	35.0	2.57	5.38	3.72
Blending	MPN-1	5	23.8	29.5	32.7	34.7	2.72	5.87	3.69
	MPN-2	10	22.5	28.0	29.0	32.8	2.57	5.23	3.57
	MPN-3	15	21.6	25.1	27.1	30.5	2.48	4.80	3.45
	MPN-4	20	15.1	18.9	21.4	22.9	2.32	4.57	3.20
	MPN-5	25	16.4	19.0	20.1	21.6	2.07	3.80	3.05
Addition	MPW-1	5	22.4	30.6	32.6	36.4	2.72	5.67	3.72
	MPW-2	10	23.1	31.4	33.7	38.6	3.04	5.91	3.94
	MPW-3	15	21.8	31.5	34.2	35.7	2.79	6.08	3.66
	MPW-4	20	21.5	30.5	32.5	33.9	2.68	5.85	3.46
	MPW-5	25	21.4	29.7	30.8	31.5	2.51	5.49	3.33
	MPW-6	30	21.6	27.1	28.1	29.7	2.43	5.12	3.08

Note: f_{cu} is the cube compressive strength of concrete at different ages; $f_{ts}$is the 28d splitting tensile strength of concrete; f_{tf} is the 28d flexural strength of concrete; E is the elastic modulus of concrete.

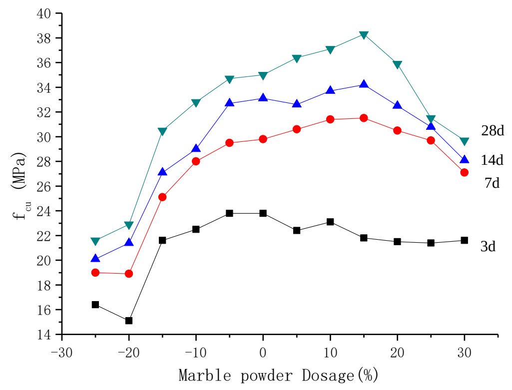


Figure 4. Relationship between compressive strength of concrete at different ages and dosage of artificial marble waste powder

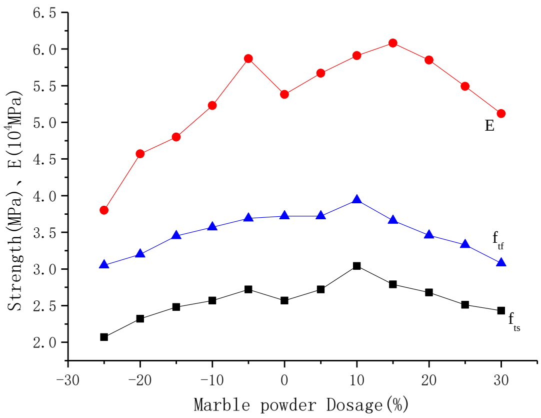


Figure 5. Relationship between fts, ftf, E and dosage of artificial marble waste powder

3.2.1. Cube compressive strength of concrete

It can be seen from Figure 4 and Table 6 that, in the MPN tests, the compressive strength of concrete decreased with the growing dosage of artificial marble waste powder, regardless of the age. Under any dosage, the concrete blocks at different ages were all less strong than the concrete in the control group. The compressive strength of the 28d block reached the minimum of 21.6MPa at the dosage of 25%, 38.3 lower than that of the control group. In the MPW tests, the compressive strength of concrete first increased and then decreased with the increase of dosage, regardless of the age. The 7d, 14d and 28d blocks reached the maximum compressive strength, 9.4% higher than that of the control group, at the dosage of 15%. The compressive strengths of these blocks were all greater than that of the control group, when the dosage was smaller than or equal to 20%.

3.2.2. Splitting tensile strength of concrete

As shown in Figure 5 and Table 6, in the MPN tests, the splitting tensile strength of concrete underwent a slight increase and then a gradual decline with the growing dosage of artificial marble waste powder. At the dosage of 5%, the splitting tensile strength peaked at 2.72MPa, 5.8% higher than that of the control group; at the dosage of 25%, the strength reached the minimum of 2.07MPa, 19.5% lower than that of the control group. By contrast, in the MPW tests, the splitting tensile strength of concrete first increased and then dropped with the increase in the dosage. At the dosage of 15%, the splitting tensile strength peaked at 3.04MPa, 18.3% higher than that of the control group; at the dosage of 25%, the strength reached the minimum of 2.43MPa, 5.7% lower than that of the control group; the splitting tensile strengths of all specimens were greater than that of the control group, when the dosage was smaller than or equal to 20%.

To sum up, the splitting tensile strength of concrete, after being blended or added with artificial marble waste powder, was about 1/10~1/14 of the cube compressive strength of concrete. This agrees well with the ratio of splitting tensile strength to cube compressive strength of ordinary concrete (about 1/10~1/20). Then, the test results were subjected to power function regression analysis. The correlation coefficient was calculated as 0.845, indicating that the simulation is of high accuracy (Figure 6).

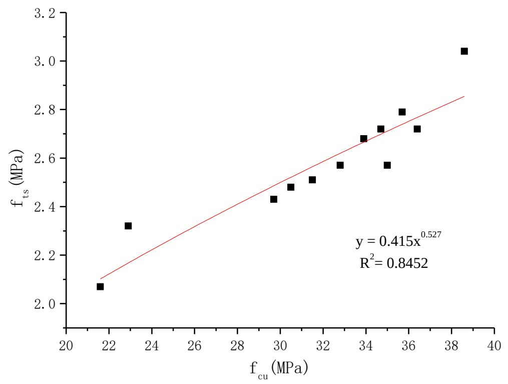


Figure 6. Relationship between splitting tensile strength and cube compressive strength of the concrete blended or added with artificial marble waste powder

3.2.3. Flexural strength of concrete

As can be seen from Figure 5 and Table 6, in the MPN tests, the flexural strength of concrete exhibited a slight increase and then a gradual decline with the growing dosage of artificial marble waste powder. At the dosage of 5%, the flexural strength peaked at 5.87MPa, 9.1% higher than that of the control group; at the dosage of 25%, the strength reached the minimum of 3.8MPa, 29.4% lower than that of the control group. By contrast, in the MPW tests, the flexural strength of concrete first increased and then fell with the increase in the dosage. At the dosage of 15%, the flexural strength peaked at 6.08MPa, 13% higher than that of the control group; at the dosage of 25%, the strength reached the minimum of 5.12MPa, 4.8% lower than that of the control group; the flexural strengths of all specimens were greater than that of the control group, when the dosage was smaller than or equal to 20%.

Next, a linear regression analysis was performed on the flexural strength and cube compressive strength of the concrete blended or added with artificial marble waste powder. The correlation coefficient was calculated as 0.995, indicating that the simulation is of high accuracy (Figure 7).

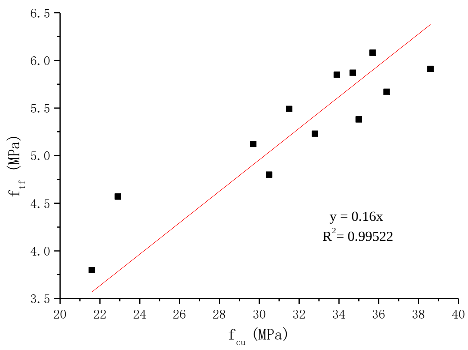


Figure 7. Relationship between flexural strength and cube compressive strength of the concrete blended or added with artificial marble waste powder

3.2.4. Elastic modulusof concrete

Figure 5 and Table 6 show that, in the MPN tests, the elastic modulus of concrete first increased and then gradually dropped with the growing dosage of artificial marble waste powder. At the dosage of 25%, the elastic modulus was minimized at 30.5GPa, 18% lower than that of the control group. In the MPW tests, the elastic modulus of concrete increased before decreasing with the growth in the dosage. At the dosage of 10%, the elastic modulus reached the maximum of 39.4GPa, 5.9% higher than that of the control group. At the dosage of 25%, the elastic modulus was minimized at 30.8MPa, 17.2% lower than that of the control group. The elastic modulus values of all specimens were greater than or equal to that of the control group, when the dosage was smaller than or equal to 10%.

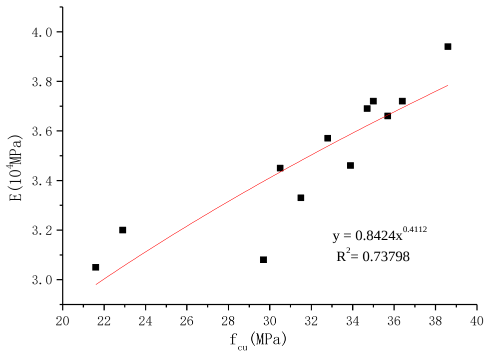


Figure 8. Relationship between elastic modulus and cube compressive strength of the concrete blended or added with artificial marble waste powder

Then, the test results on the elastic modulus and the cube compressive strengths were subjected to power function regression analysis. The correlation coefficient was calculated as 0.738, indicating that the simulation is of high accuracy (Figure 8).

3.2.5. Results analysis

In the MPN tests, the splitting tensile strength and flexural strength of concrete were slightly improved, while the compressive strength and elastic modulus of concrete declined, when the dosage of artificial marble waste powder was less than 5%. The main reasons are as follows. With a small dosage, the artificial marble waste powder was effectively and evenly dispersed into the cement, and worked with the latter to wrap up or fill in the aggregates. With a smaller particle size than cement, the powder filled up the gaps between cement particles. The ensuing growth in concrete compactness exhibited as a slight increase in strength. Further growth in the dosage caused a continuous decline in cement content of the concrete. Since the powder lacks hydration activity, the amount of cementing material in the system declined. In this case, the water-binder ratio in the system grew, for the water consumption was maintained constant. As a result, the mechanical strengths of concrete fell across the board.

In the MPW tests, the mechanical strength indices of the concrete first increased and then declined with the growing dosage. Below are the possible causes of this particular trend. In such tests, the amount of artificial marble waste powder was on the rise while the water consumption and cement volume remained the same. In this case, the water in the system not only has to satisfy the constant demand of the cement, but also meet the needs for wetting and wrapping up the additional powder. Thus, there were fewer water in the system than that in the test group. When the dosage was small, the powder filled up the gaps between the aggregates and cement particles, such that the water-binder ratio in the system dropped without changing the total volume of the system. In this way, the concrete strength underwent a gradual increase. Once the dosage was high enough, the powder started to support the system skeleton, in addition to gap filling, kicking off the expansion of concrete. Then, the cement volume in the system was relatively fewer than the control group. In other words, the MPW effect is similar to the MPN effect after the dosage reached a certain threshold, thereby lowering the mechanical parameters.

4. Conclusions

This paper carries out tests on the working performance and mechanical properties of concrete blended or added with artificial granite waste powder. Through results analysis, the following conclusions were put forward:

(1) The artificial marble waste powder can be added onto the concrete. In this case, the maximum dosage should not surpass 20%. The blending of such powder is unfavorable to concrete strength but favorable to the working performance of the concrete. In general, the author does not recommend the blending of artificial marble waste powder into concrete.

(2) Both blending and addition of artificial marble waste powder can improve the cohesiveness and bleeding of concrete. The blending is an effective way to increase the slump of concrete, while the addition suppresses the slump.

(3) During the blending of artificial marble waste powder, the splitting tensile strength and flexural strength of concrete were slightly improved, while the compressive strength and elastic modulus of concrete declined, when the dosage was less than 5%. During the addition, the strength indices of the concrete were all on the rise; the indices reached the maximum at the dosage of 10~15%, were comparable to those of the control group at the dosage of 20%, and plunged rapidly when the dosage surpassed 25%. To optimize the properties of concrete, the optimal dosage of artificial marble waste powder was determined as 15% (addition); To optimize the environmental impact, the optimal dosage was determined as 20% (addition).

(4) For the concrete blended or added with artificial marble waste powder, the relationships between the strength indices are similar to that of ordinary concrete. Specifically, the splitting tensile strength and the cube compressive strength has a power function relationship with the correlation coefficient of 0.845; the flexural strength and the cube compressive strength has a linear relationship with the correlation coefficient of 0.995; the elastic modulus and the cube compressive strength has a power function relationship with the correlation coefficient of 0.738.

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