Experimental study on anti-freezing and thawing of preparation of wet mixed mortar with full component recycled sand in plastering engineering

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Abstract. In this study, in order to study the freeze-thaw resistance of wet-mix plaster mortar after replacing artificial sand (AS) with full-component recycled sand (FCRS) and recycled brick powder (RBP) instead of fly ash (FA), ratio of binding material to fine aggregate (RBMFA) (1:5, 1:6 and 1:7), types of fine aggregate (TFA) (AS and FCRS) and kinds of mineral admixture (KMA) (FA and RBP) were considered as research variables. RBMFA, TFA and KMA have an effect on freeze-thaw resistance performance of wet mixed mortar (WMM) could be studied with the slow freezing method. Moreover, new way of application of brick powder was explored. Take advantage of full-component recycled fine aggregate instead of traditional AS to prepare wet mix plaster mortar (WMPM) have three meanings of saving natural resources, protecting the environment and achieving superior economic benefits. Numerical studies indicated that RBMFA is one of the most main influence factors of the freezing and thawing resistance of mortar. Under 25 freeze-thaw cycles, mass loss rate (MLR) and strength loss rate (SLR) of mortar increase with the reduction of rubber sand ratio, the average MLR of RBMFA 1:7 to 1:5 increased by 2.5%, and the average SLR increased by 7.4%. Replacing AS with FCRS and replacing BP with FA can not only alleviate the shortage of natural sand and FA, but also it could realize the resource utilization of building waste.

1. Introduction
Nowadays, our country's construction industry, one of the five pillar industries of national economy, developing constantly in a high speed, so that satisfy the living’s demands of human society. It was estimated that the amount of construction rubbish achieved 5×10⁹t during the period of China's development and construction until 2020[1]. Numerical studies indicated that 10⁴t old buildings would be dismantled for every 0.7-1.2t waste materials generated. The rate of resource utilization was less than 5% [2], which was far lower than American, German and French, et al developed countries (90%) and Japan and South Korean (95%). Moreover, the method of treatment of construction waste is belong to low-level utilization, that is to say simple distinguish, classify and ordinary backfilling technique are used. With the purpose of reduce the irreversible damage of construction waste to the ocean, soil and atmospheric environment, natural sand and gravel are subjected to excessive consumption. Hence, full-component recycled fine aggregate has received extensive attention from scholars and experts.
Full-component recycled fine aggregate technology is adopted by preparing full-component recycled fine aggregate [3]. Generally speaking, waste concrete can be transformed into RFA with a particle size of 4.75mm or less in the process of simple cleaning, simple crushing, cleaning again, crushing again and particle shaping orderly. Compared with ordinary recycled fine aggregate (ORFA), Full-component recycled fine aggregate is strengthened by particle shaping, result in hardened cement stone content decrease considerably on the surface of recycled aggregate, and water absorption of RFA is reduced, both water-retention rate and strength are enhanced, meanwhile, the durability of mortar would be improved.

At the beginning of the 21st century, six departments which including the State Bureau of Commerce, the Ministry of public security, the Ministry of construction, the Ministry of communications and the General Administration of quality supervision, inspection and quarantine were jointly promulgated "the notice on forbidding on-site mortar mixing in some cities within a time limit". Due to there are a number of disadvantages for mixing mortar on site such as low construction efficiency, the quality is not up to the expected goal, dust and noise pollution, e.g. [4-5]. The slogan which is "prohibit ready-mixed mortar, promote ready-mixed mortar" was came up with our country [6-8]. Following this, the advantage of ready-mixed mortar is conducive to development of bulk cement, comparing to traditional bagged cement, bulk cement have less handing workload, less affected by the atmospheric environment and low cost. It is easier to application and promotion. Ready-mixed mortar is divided into wet-mixed mortar (WMM) and dry-mixed mortar according to production process. WMM, a green building material with energy conservation and emission reduction, is made up of fine aggregate, cement, mineral admixture and additive in a certain mix proportion. Contrast dry-mixed mortar, on the one hand, as a result of WMM at first add water with mixing then transport to the construction site and use directly. Therefore, it not only would be prevented for add water with stirring for the second time, but also avoid causing dust and noise pollution [9-10]. On the other hand, concrete mixing station also could be used for production WMM, both improve work efficiency and reduce costing are realized. However, WMM was deposited within a 24-hour period. Many scholars have conducted a lot of research on the basic properties of it. Wang Yu-li [11] found that the stone powder in artificial sand (AS) can improve the mechanical properties of the mortar, and also has a great influence on its shrinkage performance. With the increase of the stone powder content, the shrinkage of the mortar first decreased and then increased. Studies had found that mortar with a stone powder content of not more than 15% has good performance [12], and AS and stone powder with a content of less than 5% has no obvious effect on the performance of the mortar. Wan Jian-cheng, et al[13] studied that sand fineness modulus and particle gradation directly exert influence on mortar strength and construction performance. The study found that CFB gangue slag has high water absorption, large crushing value, uneven particle size and poor gradation. It lead to mortar obtained higher strength and lower flow after replacing fine aggregate. Wehbe, et al. [14] studied the influence of super absorbent resin SAP on the degree of autogeneous shrinkage and hydration reaction of wet-mixed plaster mortar. The results show that both SAP and SPA could reduced the early shrinkage of cement-based materials, but when SAP is mixed with SRA, SRA The function of inhibiting SAP, the shrinkage rate is greater than that of cement-based materials when SAP alone is used, but it can improve its early hydration degree. YR Zhang [15] studied the influence of the adsorption of monomers, homopolymers and PC copolymers in cement paste on cement hydration. Studies have found that there is no adsorption and retardation of monomers in cement paste, while the corresponding copolymers have different degrees of adsorption and retardation.

At present, AS and recycled sand were chosen in research object of WMM by a plenty of scholars. Compared with natural aggregates, recycled aggregates have larger porosity, more cracks, and lower compressive strength [16]. Most areas in the north are hot in summer and cold in winter. If WMM is to be promoted in a large area in the north, the problem of frost resistance of WMM must be solved. For the sake of solve the problem with the frost resistance property of recycled mortar is generally worse, preparation of WMM with (full-component recycled sand) FCRS was carried out and freeze-thaw resistance performance was investigated in one experiment. The primary content in the experiment,
which consists of the design of mix proportion of recycled mortar, specimen production and maintenance. Apart from, the basic mechanical (such as consistency, water-retention rate and apparent density) and freeze-thaw resistance performance of WMM were monitored. Also, it could be studied by ratio of binding material to fine aggregate (RBMFA), types of fine aggregate (TFA) and kinds of mineral admixture (KMA) had an effect on the anti-freezing and thawing performance of recycled mortar. Finally, compared to three sorts of research variables, the main influence factor of freeze-thaw resistance performance of recycled mortar was produced. It plays a certain role in promoting for the wide application of green mortar and energy conservation and environmental protection to carry out the research on the preparation of WMM with FCRS.

2. Materials
The raw materials used in the experiment are cement, FCRS, AS, FA, RBP, efficient water reducer, water retaining with thickener and retarder. Cement: Portland Cement P.O 42.5 was chosen in the experiment with fineness modulus of 2.4. FCRS: it was a type of recycled sand. At first, waste concrete is crushed into recycled coarse aggregate. And then, recycled coarse aggregate particles can be reshaped and strengthened with the help of particle shaping equipment, so that cement stone, new and old cement paste on the surface of recycled aggregate is reduced. In the end, recycled aggregate is crushed again until the particle size is less than 4.75mm. Therefore, FCRS is acquired. It meets the technical requirements of class II RFA in GB/T 25176-2010 "Recycled fine aggregate for concrete and mortar". The basic parameter of FCRS are shown as Table 1. FA: two grade fly ash was used with specific surface area is equal to 336kg/m³, which fineness achieved to 24.2%. RBP: it was produced by recycled clay red brick. Additive: it was adopted by three sorts of additives. They are Naphthalene efficient water reducer of 0.85%, Methyl cellulose water retention and thickener of 0.3% and Sodium gluconate retarder of 0.1% respectively.

| Table 1. Basic properties of cement. |
|-------------------------------------|
| Fineness/% | Initial setting time /(min) | Final setting time /(min) | Flexural strength /(MPa) | Compressive strength /(MPa) |
|------------|-----------------------------|---------------------------|-------------------------|---------------------------|
|            |                            |                           | 3d 28d                  | 3d 28d                    |
| 2.37       | 163                        | 251                       | 4.15                    | 7.42                      |
|            | 17.8                        | 41.04                     |                         |                          |

| Table 2. Physic properties of fine aggregate |
|---------------------------------------------|
| TFA                                         |
| FCRS | Fineness modulus | Apparent density /(kg·m⁻³) | Stacking density /(kg·m⁻³) | Stone powder content /% | Crush index /% | Water absorption /% |
| 2.8 | 2549            | 1524                       | 2.4                       | 20.3                   | 0.8            |
| AS  | 2.9             | 2506                       | 1506                      | 9.6                    | 18.3           | 0.4             |

| Table 3. Basic physic properties of FA and RBP |
|---------------------------------------------|
| KMA                                         |
| FA   | Fineness | Loss on ignition /% | Moisture content /% | Water requirement /g |
| 17.8 | 7.4      | 1.0                | 118                |
| RBP  | 16.8     | 1.2                | 1.2                | 101                 |
Table 4. Major chemical composition of FA and RBP

| KMA | w(SiO₂) | w(Al₂O₃) | w(CaO) | w(Fe₂O₃) | w(MgO) |
|-----|---------|----------|--------|----------|--------|
| FA  | 31.63   | 29.70    | 9.74   | 20.82    | 5.42   |
| RBP | 50.81   | 27.91    | 8.46   | 5.91     | 3.08   |

3 Experimental preparation

3.1 FCRS preparation technology

In order to overcome the disadvantages of recycled aggregates such as multiple edges and corners, large porosity, high water absorption, low apparent density and low compressive strength [17], the preparation process of FCRS was proposed. In the first place, waste concrete become into recycled aggregate with a particle size of 25mm or less in the process of simple cleaning, filtration and crushing orderly. Moreover, recycled aggregate could be crushed into tiny recycled concrete with a particle size of 10—25mm. Last but not the least, Full-component recycled fine aggregate is strengthened by particle shaping, hardened cement stone content decrease considerably on the surface of recycled aggregate with high speed impact. And water absorption of RFA was reduced, both water-retention rate and strength are enhanced, meanwhile, the durability and basic mechanical property of mortar would be improved. The preparation process of FCRS is described as Figure 2.

At first, the discarded red clay bricks are collected and it is crushed into below 4.75mm with a large jaw crusher, and then grind the broken bricks with a sample crusher until it is below 45μm to obtain RBP. The production process of the brick powder is shown in Figure 3.

Figure 1. FCRS and RBP

Figure 2. The preparation process of FCRS
3.2 Experimental program and design of mix proportion
Mortar is a type of concrete which hasn't coarse aggregate. FCRWMPM consists of FCRS, cement, mineral admixture, additive and water with a certain composition ratio. It is applied in the plastering engineering. Based on the "Technical Regulations for Plastering Mortars" (JGJ/T 220—2010), the mix ratio design of the plastering mortars is based on the requirements of "Ready-Mixed Mortars" (GB/T 25181-2010). RBMFA (1:5, 1:6 And 1:7), types of fine aggregate (FCRS and AS) and types of admixtures (FA and RBP) were selected as the research variables. Select 40% of binding material, 0.85% of water reducing agent, 0.3% of water retaining thickener and 0.1% of retarder. Mix proportion of WMPM are listed in Table 5.

Table 5. Experimental design mix ratio of WMPM (kg/m³)

| Number | RBMFA | FCRS | AS | Binding material | Cement | FA | RBP | Additive |
|--------|-------|------|----|-----------------|--------|----|-----|---------|
| J-1/5-F | 1 : 5  | 0    | 1708 | 342              | 205    | 137 | 0   | 4.27    |
| Q-1/5-F | 1 : 5  | 1708 | 0   | 342              | 205    | 137 | 0   | 4.27    |
| J-1/5-Z | 1 : 5  | 0    | 1708 | 342              | 205    | 0   | 137 | 4.27    |
| Q-1/5-Z | 1 : 5  | 1708 | 0   | 342              | 205    | 0   | 137 | 4.27    |
| J-1/6-F | 1 : 6  | 0    | 1757 | 293              | 176    | 117 | 0   | 3.66    |
| Q-1/6-F | 1 : 6  | 1757 | 0   | 293              | 176    | 117 | 0   | 3.66    |
| J-1/6-Z | 1 : 6  | 0    | 1757 | 293              | 176    | 0   | 117 | 3.66    |
| Q-1/6-Z | 1 : 6  | 1757 | 0   | 293              | 176    | 0   | 117 | 3.66    |
| J-1/7-F | 1 : 7  | 0    | 1794 | 257              | 154    | 103 | 0   | 3.21    |
| Q-1/7-F | 1 : 7  | 1794 | 0   | 257              | 154    | 103 | 0   | 3.21    |
| J-1/7-Z | 1 : 7  | 0    | 1794 | 257              | 154    | 0   | 103 | 3.21    |
| Q-1/7-Z | 1 : 7  | 1794 | 0   | 257              | 154    | 0   | 103 | 3.21    |

\( ^a \) where Q and J respectively expressed as AS and FCRS.

\( ^b \) where Z and f respectively expressed as RBP and FA.

3.3 The experimental method
The freeze-thaw resistance performance of WMPM was determined to JGJ/T 70-2009, "Standard for basic performance experiment method of building mortar" by slow freezing method. The freeze-thaw mechanism of slow freezing method is air freezing and water thawing, number of freeze-thaw cycles was set to 25 times, MLR and SLR can be used to describe material anti-frost property accurately.

Under the conditions of 25 cycles of positive and negative temperature, free water in the larger hole is frozen in the specimen, it can be expanded with forming a part of ice crystals. With the increase of the number of freeze-thaw cycles, free water in the smaller pore is became ice crystals as well,
specimen internal structure had been expansionary affected by a large number of ice crystals. When the action of expansion more than the capacity of pressure-bearing of internal structure, there is damaged. Part of the broken fine mortar particles will be lost along with the moisture migration in the mortar. Ultimately, it caused that mass loss of mortar specimen, which represent for MLR. Due to broken fine mortar particles decrease with the decrease of water, this results in a decrease of compactness of inner structure, a decline of compressive strength and an increase of compressive strength loss of mortar specimen. It is shown as SLR.

3.4 Specimen production and maintenance

The feeding method of WMPM is to add powder to mix evenly. And then add water, which makes the dry powder and mortar mix more evenly and the fluidity of mixture better. Mixing time is controlled by 150s, it should be broken up four phases: dry mix 40s, add water with mixing 40s, rapid mix 40s and slow mix 40s. Because of mortar consistency are bigger than 50mm, tamping molding was used as the approach of molding, to be specific, insert the tamping rod homogeneous in the mortar from outside to inside for 25 times. These specimens are kept in the curing room where the temperature of 20±2℃ and humidity larger than 90%.

4. Experimental results and analysis

4.1 Relationship between consistency and freeze-thaw resistance property of WMM

Base on above frost heave principle could be demonstrated that the increase of water consumption led to the mortar is frozen more easily, MLR and SLR are increased. Thereby, anti-freezing and thawing performance can be deteriorated to some extent. Therefore, the water consumption of mortar is inversely proportional to the frost resistance. On account of relationships between MLR-the initial consistency and SLR-the initial consistency have certain linearity, MLR and SLR are influenced by various factors at the same consistency can be investigated. In order to come true quantitative analysis precisely, the water consumption of mortar should be controlled relatively stable. Because of standard range of consistency is larger, on the one hand, consistency exert influence on water consumption of mortar, on the other hand, it also has impact on anti-freezing and thawing performance of mortar. So, the linear regression of the initial consistency—MLR and the initial consistency—SLR were carried out. In the first place, data in Table 3 and Table 4 are chosen and it can be drawn that relationship graphs of the initial consistency—MLR and the initial consistency—SLR (It is shown as Figure 4 and Figure 5). Apart from, the regression relationship of the initial consistency—MLR and the initial consistency—SLR can be understood by the following formula in Table 6 through linear regression. Finally, the water consumption of WMPM consistency at 70mm, 90mm and 110mm respectively are calculated.

Figure 4. Measured consistency-MLR diagram
Table 6. Regression relation between freeze-thaw damage evaluation index and measured consistency

| Number | Parameter       | Regression equation | Correlation coefficient | Number | Parameter       | Regression equation | Correlation coefficient |
|--------|-----------------|---------------------|-------------------------|--------|-----------------|---------------------|-------------------------|
| J-1/5-F | MC-$\Delta m_m$ | $y=0.2053x-4.3614$ | $R^2=0.871$ | J-1/5-Z | MC-$\Delta m_m$ | $y=0.1906x-0.6215$ | $R^2=0.931$ |
|        | MC-$\Delta f_m$ | $y=0.2014x-4.642$  | $R^2=0.856$ |        | MC-$\Delta m_m$ | $y=0.0529x-2.7314$ | $R^2=0.907$ |
| J-1/5-Z | MC-$\Delta m_m$ | $y=0.2014x-4.462$  | $R^2=0.856$ | J-1/5-Z | MC-$\Delta f_m$ | $y=0.2000x-2.2000$ | $R^2=0.915$ |
|        | MC-$\Delta f_m$ | $y=0.1749x+2.3508$ | $R^2=0.801$ |        | MC-$\Delta f_m$ | $y=0.2452x-2.7613$ | $R^2=0.985$ |
| J-1/6-F | MC-$\Delta m_m$ | $y=0.0514x-1.7404$ | $R^2=0.882$ | J-1/6-Z | MC-$\Delta m_m$ | $y=0.0668x-2.7990$ | $R^2=0.937$ |
|        | MC-$\Delta f_m$ | $y=0.1764x+1.6346$ | $R^2=0.890$ |        | MC-$\Delta f_m$ | $y=0.2419x-3.2082$ | $R^2=0.990$ |
| J-1/6-Z | MC-$\Delta m_m$ | $y=0.0575x+0.825$  | $R^2=0.998$ | J-1/7-F | MC-$\Delta m_m$ | $y=0.0618x-0.7724$ | $R^2=0.992$ |
|        | MC-$\Delta f_m$ | $y=0.1927x+4.5936$ | $R^2=0.884$ |        | MC-$\Delta f_m$ | $y=0.2125x+1.875$  | $R^2=0.915$ |
| J-1/7-F | MC-$\Delta m_m$ | $y=0.0575x+1.395$  | $R^2=1.000$ | J-1/7-Z | MC-$\Delta m_m$ | $y=0.0733x-2.1502$ | $R^2=0.989$ |
|        | MC-$\Delta f_m$ | $y=0.1853x+4.7207$ | $R^2=0.856$ |        | MC-$\Delta f_m$ | $y=0.2273x+1.2336$ | $R^2=0.989$ |

The results from Figure 3, Figure 4 and Table 6 indicated that measured consistency-MLR($\Delta m_m$) and measured consistency-SLR($\Delta f_m$) are linear fitted, relationship of consistency-MLR and consistency-SLR have favorable linearity, correlation coefficient more than 0.8. MLR and SLR increased with the increase of measured consistency. When the consistency increased by 10mm, MLR increased by 0.6% and SLR increased by 2.1% of FCRSM. While the consistency increased by 10mm, MLR increased by 0.5% and SLR increased by 1.8% of ASM. When measured consistency isn't less than 104mm, the value of $\Delta f_m$ and $\Delta m_m$ of J-1/7-F, J-1/7-Z, Q-1/7-F and Q-1/7-Z exceed to 5% and 25% limiting value in "Ready-mix mortar" (GB/T 25181-2010) under 25 freezing and thawing cycles. Actual engineering requirements couldn't be satisfied. Thus, RBMFA should larger than 1:7, measured
consistency wasn’t greater than 104mm.

4.2 Effect of RBMFA on anti-freeze resistance of mortar

Although MLR and SLR of different initial consistency are different, the laws of MLR and SLR of the same consistency are uniformity. In order to reflect the influence of the RBMFA on the antifreeze performance, the value of $\Delta f_m$ and $\Delta m_m$ at standard consistency 70mm, 90mm and 110mm could be calculated by 24 groups regression equation and Table 6. Meanwhile, the influence law of consistency-MLR and consistency-SLR of WMPM under different RBMFA at three varieties of consistency are shown in Figure 4.

Figure 6. The influence law of the RBMFA to WMPM’s MLR after 25 freeze-thaw cycles

![Figure 6](image)

(a) the value of consistency 70mm  
(b) the value of consistency 90mm  
(c) the value of consistency 110mm

Figure 7. The influence law of the RBMFA to WMPM’s SLR after 25 freeze-thaw cycles

![Figure 7](image)

(a) the value of consistency 70mm  
(b) the value of consistency 90mm  
(c) the value of consistency 110mm

When the mineral admixture content is constant, as RBMFA decreased, water consumption of mortar increased and the free water inside the mortar increased accordingly. It caused that ice crystal expansion more significant, which MLR and SLR of mortar greatly increased. In addition, RBMFA was reduced, the amount of admixtures was reduced, both FA and BP have a kind of filling effect, the filling effect could be reduced. The moisture content increased, MLR and SLR increased too, so the mortar is more severely damaged by freezing and thawing.

After 25 freeze-thaw cycles, MLR and SLR of mortar increased with the decrease of the RBMFA, which the growth rate was more obvious. When RBMFA was reduced from 1:5 to 1:7, MLR of mortar increased by an average of 2.4%, and MLR was basically linear with RBMFA SLR increased by an average of 7.4%. When RBMFA reached 1:7, both MLR and SLR of mortar reached the maximum, which were 4.4% and 22.6% respectively.

4.3 Effect of TFA on anti-freeze resistance of mortar

The freeze-thaw damage of FCRS mortar is greater than AS mortar. There are three reasons as follows: Firstly, the surface of the FCRS contains a small amount of cement slurry and a great deal of tiny cracks, the water absorption rate of FCRS is one time higher than AS. In addition, water consumption
is increased when preparing mortar, RBMFA became larger in actually, free water in mortar specimen grow in quantity result in MLR and SLR of WMPM improved when it was exposed to action of freezing and thawing cycle. Secondly, there are a large amount of micro-cracks and hardened cement stones attached in the surface of FCRS, it is easier to damage after freeze-thaw cycle at the week interface and leading to MLR and SLR growing faster. Thirdly, the content of stone powder in the fine aggregate is less than 10% contribute to improve the frost resistance of the mortar, because some of the micro pores and cracks filled with an appropriate amount of stone powder in the mortar, further improve the overall density of the mortar. While other situation hasn’t be changed, MLR and SLR of WMPM of FCRS are 0.5% and 1.7% higher than AS respectively. When the RBMFA is greater than 1:7, the degree of freeze-thaw damage of AS mortar is more sensitive to the consistency value than FCRSM. When RBMFA is equal to 1:7, the consistency of FCRSM is sensitive higher. In conclusion, WMPM of FCRS has inferior frost resistance performance compared with AS.

4.4 Effect of KMA on anti-freeze resistance of mortar

FA mineral admixture is mainly made up of SiO$_2$, Al$_2$O$_3$ and CaO et al with pozzolanic active glass, nevertheless, the main component of BP is mullite, which is a 3Al$_2$O$_3$·2SiO$_2$ compound with barely any activity. BP below 45μm is obtained by mechanical grinding by physical method, which is used to fill the small gaps in the mortar and make the mortar structure more compact [19]. Water consumption of BP is more than FA slightly. However, water absorption of BP is higher, it could be more likely to caused free water of mortar reduced. It was not obvious that effect of ice crystal expansion inside the mortar, which MLR and SLR of BP are less than FA. Besides, specific surface area of BP larger than FA, it has superior filling effect. The density of the mortar is improved, free water of the internal structure was reduced and MLR and SLR were reduced. Therefore, freeze-thaw resistance property of BP mortar is superior than FA mortar. When other conditions remain unchanged, MLR and SLR of mortar mixed with BP were smaller than those with FA. MLR and SLR of BP WMPM were lower than that of FA by 0.3% and 0.8%. Whether it is AS or FCRS, the degree of freeze-thaw damage of brick mortar was more sensitive to the consistency value than fly ash mortar.

5. Conclusions

This paper shown the results on the anti-freeze performance experimental study on FCRS preparation of WMPM. The influence of three research variables on the freeze-thaw resistance of WMPM was analyzed and contrasted. The following conclusions can be listed in:

(1) Relationship consistency-MLR and consistency-SLR have a benign linearity, the larger consistency of mortar, the higher MLR and SLR of them. For every 10mm increased in consistency. MLR increased by 0.6% an average and SLR increased by 2.1% on average.

(2) When other conditions are certain, MLR and SLR of mortar increased with the decrease of RBMFA, MLR of RBMFA risen by 2.5% on average from 1:7 change to 1:5, which SLR increased by 7.4% on average from 1:7 to 1:5. MLR and SLR of FCRS preparation on WMPM were greater than AS, the difference value reached at 0.5% and 1.7% approximately, MLR and SLR of mortar of adding BP were 0.3% and 0.8% less than mixed with FA respectively. In three types of research variable, RBMFA is the most primary reason on freeze-thaw resistance property of mortar.

(3) When RBMFA more than 1: 7, the degree of freeze-thaw damage of AS mortar was more sensitive to the consistency value than FCRS mortar. When RBMFA is 1:7, FCRS mortar was more sensitive to the consistency. The degree of freeze-thaw damage of BP mortar was more sensitive to the consistency value than FA mortar.

(4) Although, anti-freeze property of mortar of numerical studies indicate that FCRS-BP<AS-FA, the difference value in MLR is 0.23% and SLR is 0.93%. Among AS-FA, AS-BP, FCRS-FA and FCRS-BP can be satisfied with various performance indicators. Replacing AS with FCRS and replacing BP with FA can not only alleviate the shortage of natural sand and fly ash, but also it could realize the resource utilization of building waste.
Acknowledgments
This work was supported by Shenyang Science and Technology Bureau project (20-206-4-11) and Science and technology projects of Liaoning Provincial Department of Communications (202007).

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