Effect of Recycled Fine Powder and Mineral Admixture on the Properties of the Cement Mortar

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Abstract. By studying the effect of recycled fine powder and its recombination with fly ash and silica fume on the compressive and flexural strength of the mortar, to explore the feasibility of reusing the powder. The research results show that the recycled fine powder is an "inert material", which will reduce the compressive and flexural strength of the mortar. The fly ash can improve the negative effect of the powder on the flexural strength, but it has little effect on the compressive strength. After fly ash and silica fume are mixed, it can obviously improve the inhibitory effect of the powder on the compressive and flexural strength of the mortar. Therefore, it can be concluded that when recycled fine powder, fly ash and silica fume are blended at a ratio of 5:4:1 to replace 20% of the cement, it can be used as a cementitious material instead of cement to make the mortar that meet the strength requirements, thereby conserving resources.

1. Introduction

Recycled fine powder is a fine particle obtained from crushing and sieving operations of waste concrete, it’s an inert material with a size less than 0.16mm [1]. Fly ash is the waste ash discharged after the coal is burned. And silica fume is an smelting industrial dust that emitted when high-purity quartz and coke react at high temperatures. The annual production volume of construction waste is huge in China, and the main methods of disposal are open storage and landfill. The annual emissions of fly ash and silica fume are also very large, and they are growing year by year. If these wastes are ignored, they will certainly affect the natural environment and endanger human health.

Studies have shown that the recycled fine powder has a filler effect and can theoretically be used as a mineral admixture, but its utilization rate is not significant when processing is not carried out [2-3]. Saeed Ahmari and Xin Ren et al. [4], who showed that the use of recycled fine powder and fly ash can produce geopolymeric binder that meet the strength requirements. Dae-Jung Moon et al. [5] concluded that recycled fine powder would reduce the fluidity of cement mortar. Studies by Liu Dong et al. [6] point out that the powder has potential activity and that this potential activity can be stimulated by adding a chemical activator. Yu Xiaoxiao and Li Ruyan et al. [7] showed that the powder particles are irregular and the granularity is not uniform, and can be used to make high-strength cement mortar as an admixture after grinding by a ball mill. Silica fume and fly ash have unique chemical activity and physical properties, both of which are common mineral admixtures. The study found that silica fume in concrete can improve its early compressive strength, but it will have an adverse impact on slump. Fly ash can improve the workability of concrete, but it will reduce early strength. While silicon fume and fly ash are mixed, it can improve the performance of the concrete under a reasonable composite ratio better as a results of formed a admixtures with various properties [8-9]. The research work on the partial
replacement of cement with mineral admixtures can contribute to the reduction of cement consumption, it has significant economic significance and broad application prospects, saving resources and protecting the environment to some extent.

2. Experimental program

2.1. Materials
Domestic drinking water was used in this investigation. Cement uses 42.5 grade ordinary portland cement (P.O 42.5) produced by Jinyuan Company Limited, Huzhu County, Qinghai Province, China. The sand uses the ISO standard sand produced by Xiamen Aishou Standard Sand Company Limited, with good particle size distribution. The recycled fine powder was obtained by crushing and screening of abandoned laboratory concrete. Both silica fume and fly ash are produced by Hengnuo Filter Material Company Limited, Gongyi City, Henan Province, China. And the fly ash level is grade-I. XRF analysis was performed on cement, recycled fine powder (RFP), fly ash (FA) and silica fume (SF). The main chemical composition is shown in Table 1.

| Program | SiO$_2$ | CaO | Al$_2$O$_3$ | Fe$_2$O$_3$ | SO$_3$ | MgO | K$_2$O |
|---------|---------|-----|-------------|-------------|--------|------|--------|
| Cement  | 19.8    | 40.4 | 7.67        | 2.66        | 2.31   | 2.06 | 0.95   |
| RFP     | 33.3    | 27.4 | 8.1         | 3.61        | 1.19   | 2.66 | 1.39   |
| FA      | 21.5    | 1.27 | 15.2        | 1.36        | 0.239  | 0.403| 0.678  |
| SF      | 97.3    | 0.439| 0.399       | 0.065       | 0.226  | 0.436| 0.744  |

2.2. Method

Table 2. Test proportion of mortar.

| NO. | Substitution rate(%) | FA+SF (%) | FA:SF | Cement (g) | RFP (g) | FA (g) | SF (g) | Water (g) | Sand (g) |
|-----|----------------------|-----------|-------|------------|---------|--------|--------|-----------|----------|
| A1  | 0                     | 0         | -     | 450        | 0       | 0      | 0      | 225       | 1350     |
| B1  | 20                    | 0         | -     | 360        | 90      | 0      | 0      | 225       | 1350     |
| B2  | 40                    | 0         | -     | 270        | 180     | 0      | 0      | 225       | 1350     |
| C1-1| 20                    | 30        | 1:0   | 360        | 63      | 27     | 0      | 225       | 1350     |
| C1-2| 20                    | 50        | 1:0   | 360        | 45      | 45     | 0      | 225       | 1350     |
| C2-1| 40                    | 30        | 1:0   | 270        | 126     | 54     | 0      | 225       | 1350     |
| C2-2| 40                    | 50        | 1:0   | 270        | 90      | 90     | 0      | 225       | 1350     |
| D1-1| 20                    | 30        | 4:1   | 360        | 63      | 21.6  | 5.4    | 225       | 1350     |
| D1-2| 20                    | 50        | 4:1   | 360        | 45      | 36    | 9      | 225       | 1350     |
| D2-1| 40                    | 30        | 4:1   | 270        | 126     | 43.2  | 10.8  | 225       | 1350     |
| D2-2| 40                    | 50        | 4:1   | 270        | 90      | 72    | 18     | 225       | 1350     |

2.2.1. Strength test. When the total amount of cementitious materials is not changed, RFP and RFP+FA (FA replaces RFP by 30% and 50% respectively) and RF+FA+SF (FA+SF replaces RFP by 30% and 50% respectively, FA:SF=4:1) three admixture systems replace cement with 20% and 40% additions. And in accordance with GB/T17671-1999 to prepare mortar specimens, including W/C is 1:2, C/S is 1:3. Finally, test their compressive strength and flexural strength after curing for 3d, 7d, and 28d in the standard curing conditions. The cement control group is denoted as “A”, the single-doped recycled fine powder group is denoted as “B”, the compounded recycled fine powder and fly ash group is denoted as “C”, and the recombined recycled fine powder, fly ash and silica fume group is denoted as “D”. The test proportion is shown in Table 2.
2.2.2. **Microstructure.** After the strength test of mortar, 28d broken specimens were subjected to SEM testing, and the microstructure and hydration conditions were analyzed. The SEM equipment uses a JSM-6610LV X-ray fluorescence spectrometer. Before testing, the sample was soaked in absolute ethanol and sealed to prevent the mortar sample from further hydrating.

3. **Results and discussion**

3.1. **Effect of recycled fine powder on the strength of cement mortar**

Figure 1 shows that when the content of recycled fine powder is 20% (B1), the compressive strength and flexural strength of the mortar are lower in each age than in the control group (A1), but the early flexural strength increases rapidly. With the increase of the amount of recycled fine powder, the strength of mortar decreased significantly, and the speed of development with age became slower. It can be seen that the effect of recycled fine powder on the strength of cement mortar is negative.

![Figure 1](https://example.com/figure1.png)

(a) Compressive strength  
(b) Flexural strength

**Figure 1.** Influence of recycled fine powder on strength of mortar.

3.2. **Effect of different admixture systems on the strength of mortar at 20% substitution rate**

![Figure 2](https://example.com/figure2.png)

(a) Compressive strength  
(b) Flexural strength

**Figure 2.** The effect of 20% substitution rate on the strength of mortar.

Figure 2 shows that when the substitution rate of the three medium admixtures is 20%, the compressive strength of the recycled fine powder group-B1 at each age is lower than that of the control group A1 and three-combination group-D1 that the recycled fine powder, fly ash and silica fume mixed. It’s compressive strength at 7d and 28d was slightly higher than two-combination group-C1 that the powder and fly ash mixed. The compressive strength-3d of the three-combined group-D1 was higher than control group, but the compressive strength-7d was opposite. The compressive strength-28d of the
group-D1-1 was slightly higher than that of the control group, but the group-D1-2 was lower than Control group. For the flexural strength, the flexural strength-28d of three admixture systems was similar and higher than that of the control group. The flexural strength-3d of group-D1 was not significantly different from that of the control group, and the flexural strength at 7d was slightly higher than that of the control group. The flexural strength at 3d and 7d of the group-B1 and group-C1 was significantly lower than that of the control group, but its subsequent development become faster.

In summary, at a substitution rate of 20%, the impact of waste powder on the compressive strength of the mortar is negative, and the addition of fly ash did not improve the situation even if the amount of fly ash was increased. When adding fly ash and silica fume at the same time, it can significantly improve the negative effect of recycled fine powder on the compressive strength of the mortar, and the improvement effect is more obvious with the increase of the addition amount. For the flexural strength, the effect of waste powder on mortar is negative, also. Fly ash and silica fume all promote the flexural strength of waste powder mortar, but the promotion effect has little to do with the dosage. It can be seen that when recycled fine powder, fly ash, and silica fume are mixed with 20% of cement at a ratio of 5:4:1, they can be used as an admixture to partially replace cement, thereby conserving resources.

3.3. Effect of different admixture systems on the strength of mortar at 40% substitution rate

![Graph](image-url)

**Figure 3.** The effect of 40% substitution rate on the strength of mortar

As can be seen from Figure 3, when the dosages of the three systems are both 40%, the compressive strength of the single-doped recycled powder group and the combination group at each age is lower than that of the control group-A1. The compressive strengths of two-combination group-C2 at 3d and 28d were slightly higher than that of the single-doped waste powder group-B2, it’s compressive strength-7d was similar to control group. The compressive strength-7d of the three-combination group-D2 was slightly higher than that of the group-B2 and group-C2, and the fastest growth rate of strength in the later period was significantly higher than that of the group-B2 and C2. For the flexural strength, the early flexural strength of three systems was significantly lower than that of the control group, but the later-period flexural strength of the combination group increased fastest and was higher than waste powder group-B2. The group-D2-2 had the highest flexural strength at the later stage and was almost equal to the control group.

The analysis of the above results shows that although the recycled fine powder contains high content of SiO2 and CaO, its larger particle size will cause the mortar to form a large number of pores, thereby reducing the compressive and flexural strength of the mortar, and therefore it is a kind of “inert material”, and with the increase of the amount, the more obvious the strength of the mortar decreased. Because of the fly ash has a spherical shape and smooth surface, it can play a certain “ball action” to reduce the friction between the particles, improve the fluidity of the mortar, and thus can improve the negative impact of flexural strength that waste powder on cement mortar, but have no obvious effect to
compressive strength. Silica fume is an ultra-fine particle, which can better fill the gap formed by adding recycled fine powder in mortar. Thus better improving the inhibitory effect of recycled fine powder on the strength of mortar.

3.4. Microstructure
As can be seen from Figure 4, when single-doped recycled fine powder only, the interior of the mortar has a looser texture and a large amount of pores than the control group, which is the main reason for the decrease of the strength of the mortar contained waste powder. When combined recycled fine powder with fly ash, the texture of the rubber sand is similar to that of the single-doped waste powder. But its internal hydration is relatively complete and has a certain amount of fibrous hydration products, so fly ash can improve the flexural strength of mortar, but it is not significant to the improvement of compressive strength. When combined recycled fine powder with fly ash and silica fume, the texture of the gel tends to be dense, so it can show higher strength.

![Figure 4. SEM image of mortar at 28d.](image)

4. Conclusion
a. When the content of recycled fine powder is more than 20%, it cannot be used as an admixture to partially replace cement. With the increase of the content of cement, the strength of cement mortar decreased more obviously.

b. When the mixing amount of recycled fine powder and fly ash is 20%, only the flexural strength of the mortar meet the requirements. Fly ash to a certain extent can improve the impact of recycled fine powder on the flexural strength of the mortar, and there is basically no improvement in the compressive strength. When the mixing amount is more than 20%, the improved flexural strength can not meet the requirements.

c. When the mixing amount is 20%, if the recycled fine powder, fly ash and silica fume are compounded at a ratio of 5:4:1, it can be used as an admixture to partially replace the cement. When both fly ash and silica fume are added to mortar with waste powder at the same time, the negative effect of the powder on the compressive and flexural strength of the mortar can be significantly improved. However, when the amount exceed 20% and reach 40%, the mortar strength cannot meet the requirements.
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