Effect of Limestone Powder on Mechanical Properties of Engineering Cementitious Composites

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Abstract: The effect of limestone powder replacing fly ash on the mechanical properties of engineering cementitious composites was investigated. The results showed that the water demand of engineering cementitious composites due to partial replacement of fly ash by limestone powder, but the water demand of the system decreased when the replacement ratio reached 100%. The flexural strength of the specimen appears to decrease with increasing age due to incomplete replacement of lime powder. The toughness of the specimen can be significantly improved due to the complete replacement of fly ash by limestone powder.

1. Introduction
Engineering cementitious composites (ECC) is a cementitious material that uses the principles of fracture mechanics and micromechanics to consciously design and adjust short fiber chaotically toughened cementitious composite materials [1,2]. Compared with traditional cement-based materials, it has obvious advantages in tensile resistance, crack control, and fatigue resistance. Therefore, it has broad application prospects in the field of structural engineering. For example, Endait [3] explored the application of ECC in the reinforcement and protection of masonry structures, and the results showed that the maximum bearing capacity of the reinforced structure increased by 11%, and the deflection increased by 10% after the structure was completely destroyed. Lim reported [4] that ECC can effectively capture interface cracks and eliminate surface spalling, thereby prolonging the service life of the structure.

With the maturity of mineral admixture technology, the demand for fly ash (FA), slag and other mineral admixtures in the construction industry is increasing. Restricted by region, transportation cost and supply season, there is a shortage of FA in many areas. Studies have found that limestone powder (LSP) is an ideal choice, and some countries have applied limestone powder to concrete and achieved good results. Knop [5] found that limestone powder used in the cement system played a nucleation effect, accelerated the rate of hydration, and improved the degree of cement hydration. The addition of limestone powder with a good morphology also promoted the dispersion of cementitious materials [6]. The "ball" effect like FA increased the fluidity of the cementitious materials. In addition, limestone powder with large specific surface area can be filled in the voids of the system to increase the compactness of the structure, which is beneficial to strength and durability [7].

In this paper, limestone powder was used to replace fly ash as an active admixture to prepare ECC. The influence of LSP on the mechanical properties of ECC was studied, in order to contribute to the application of LSP in ECC.
2. Experimental program

2.1. Materials
The ordinary Portland cement (P.O. 42.5R) was purchased from Sichuan Esheng Cement Co., Ltd. Cement. It had a density and specific surface of 3.1 g/cm³ and 4110 cm²/g, respectively. I class FA, microbeads and silica fume was used as supplementary cementitious materials. I class FA with d50 of 12.48 μm and density of 3.0 g/cm³ was purchased from a plant of Yibin city in China. The microbead with surface area of 3960 cm²/g was produced by a plant in Sichuan. Silica fume with a specific surface area of 10900 cm²/g was purchased from a plant in Shandong Province. To obtain strain-hardening performance, PVA fibres with a diameter of 39 μm, a length of 6 mm, are used in ECC. To improve workability of ECC mixtures, a high-efficiency polycarboxylic acid water reducing agent with a water reduction rate of 32% was used as the chemical admixtures. And, in order to reduce the air content in the system, defoamer produced sichuan new material technology Co., Ltd was introduced into the ECC. 200 mesh quartz sand was used as fine aggregate, and 200 mesh limestone powder was used to replace FA.

2.2. Mixture proportions
The mixture proportion of control is shown in Table 1. On the basis of the control, the mixture proportion is adjusted by changing the content of LSP. Four different mixtures, with the proportions given in table 2, were considered in this paper. The fiber admixture for all ratios was 2% by volume.

| Mix proportion     |       |
|--------------------|-------|
| Cement / (kg·m⁻³) | 600   |
| m (fly ash) / m (cement) | 1.0  |
| m (silica fume) / m (cement) | 0.12 |
| m (microbeads) / m (cement) | 0.08 |
| m (quartz powder) / m (binder) | 0.27 |
| m (superplasticizer) / m (binder) | 0.005 |
| m (water) / m (binder) | 0.2  |

| Mix ID | Mass of Limestone powder by fly ash /wt.% |
|--------|------------------------------------------|
| LP0    | 0                                        |
| LP33   | 33                                       |
| LP67   | 67                                       |
| LP100  | 100                                      |

2.3. Preparation and cast of the test specimens
ECC are mixed by a twin-shaft forced mixer. The first step is to mix the dry powder, the second step is to add the water reducing agent and water, and the third step is to add the fiber. Formed specimens of different sizes were cured at ambient temperature (temperature 30 ℃, humidity 70%) for 24 h and then demolded and cured to 3 d, 7 d and 28 d at 20 ± 2 ℃ and 95% relative humidity. Refer to GB/T 17671-1999 "Test method for cementitious sand strength (ISO method)" to test the flexural and compressive strength of the specimens.

3. Results and discussion

3.1. Compressive strength and flexural strength
ECC specimens were tested for compressive strength and flexural strength determination at the ages of 3, 7 and 28 days. The results of compressive and flexural strength tests are shown in Figure 1. The compressive strength of the specimens had a small change with the content of LSP. When the content is
0 and 33%, the compressive strength of the specimen was similar. After FA was completely replaced (100%), the flexural strength of specimens showed different trends. When the replacement content of LSP was less than 100%, the flexural strength of the specimen decreased with the development of age. And the replacement content of reached 67%, the flexural strength decreased greatly, but when the content increased to 100%, the flexural strength of the specimens increased continuously (as shown in figure 2, $F_{3.7d}/F_{3d}$ indicates the ratio of the increase in flexural strength from 3d to 7d to the strength at 3 days).

As the content of LSP increased (0%-67%), the water required for sample mixing increased, and the water-binder ratio increased from 0.2 to 0.24. However, the amount of water required by the system was reduced due to the fly ash was completely replaced by LSP. Slurry (LP100) with better fluidity can be obtained when the water-binder ratio was 0.2.

3.2. Fracture toughness
The flexural and compressive strength of the sample can characterize the fracture toughness of the specimen. Figure 3 showed the ratio of flexural and compressive strength of the prepared ECC specimens. With the increase of LSP content, the compression ratio of the specimen showed a trend of first increasing and then decreasing at the age up to 3 days. Specimen with the 67% replacement content of LSP, the compression ratio is 0.5, was measured the largest compression ratio at 3 days. simultaneously, the compression ratio of the specimen decreased greatly in the range of 0%-67% as development progressed. And the toughness of the specimen continued to decrease.
4. Conclusions
This work investigated the effect of a replacement rate of LSP by FA on the mechanical properties of ECC mixtures. The following conclusions can be drawn based on the experimental results:

(1) The use of limestone powder to completely replace fly ash allows the preparation of ECC with good flowability at low water-cement ratio.

(2) The partial replacement of fly ash by limestone powder caused the flexural strength of the specimens to decrease with increasing age, but the flexural strength of the specimens continued to increase after the complete replacement of fly ash.

(3) The use of limestone powder as a dopant can significantly improve the toughness of the specimens.

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