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# Effect of Air Entraining Agent on Uniaxial Tensile Properties of PVA-ECC

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**Abstract:** In this paper, polyvinyl alcohol (PVA) fiber reinforced ECC (Engineered Cementitious Composites) mortar was selected as the research object. The effect of air entraining agent on the tensile properties of PVA-ECC was studied by uniaxial tensile test with different dosages. The results showed that the tensile strength reduced by adding air entraining agent. When the amount of fly ash increased with adding a large amount of air entraining, the tensile strain reduced. In addition, the tensile strain of the cementitious material with no fly ash increased when incorporating air entraining agent.

## 1. Introduction

In order to overcome the disadvantages of low tensile strength, poor toughness and crack width control, high toughness cementitious composite (Engineered Cementitious Composite, ECC) was invented. This kind of material reinforced by short fiber was designed on micro mechanics and fracture mechanics principle with significant strain hardening and multiple cracking characteristics. The content did not exceed 2.5% of the total volume. The ductility and fracture had high control ability with the ultimate tensile strain of more than 3% [1-5]. Some scholars [6,7], in order to increase the ultimate tensile strain and tensile strength of the concrete, treated the surface of PVA fiber to reduce the chemical bonding force of the fiber substrate interface. In this paper, a large number of uniform, stable and closed microbubbles were introduced into the ECC with different proportioning ratios to change the bonding interface between the fiber and the matrix. The effect of air entraining agent on the tensile properties of PVA-ECC was discussed.

## 2. Experiment profiles

### *2.1 Materials and mix proportion*

The cement was P O 42.5 cement. The mesh of quartz sand was 200. The density of II grade fly ash was 2.31 g/cm$^3$. The air entraining agent was FLOTAGE AE-1 produced by a company in China. PVA fiber was K-II REC15 fiber produced by Japanese Kuraray Company. The mechanical and geometric properties of PVA fiber are listed in Table 1. The fiber content was 1.25% of the material by mass and the water binder ratio was 0.33. The mix proportion is shown in Table 1.

**Table 1.** Mechanical properties of PVA fiber**.**

| Fiber | Tensile strength(MPa) | Length (mm) | Diameter (μm) | Density (g cm$^{-3}$) | Elasticity modulus (GPa) |
|---|---|---|---|---|---|
| PVA | 1600 | 12 | 39 | 1.3 | 42.8 |

**Table 2.** Mixture proportions of fiber cement-based materials.

| sample | Cement | Fly ash/ Cement | Silica sand/B | Air entraining agent |
|---|---|---|---|---|
| A | 386 | 2.2 | 0.36 | 0 |
| B | 386 | 2.2 | 0.36 | 0.62（0.05%） |
| C | 386 | 2.2 | 0.36 | 1.3（0.1%） |
| D | 1233 | 0 | 0.36 | 0 |
| E | 1233 | 0 | 0.36 | 0.62（0.05%） |
| F | 1233 | 0 | 0.36 | 1.3（0.1%） |
| G | 1113 | 0 | 0.51 | 0 |
| H | 1113 | 0 | 0.51 | 0.62（0.05%） |
| I | 1113 | 0 | 0.51 | 1.3（0.1%） |

B – Binder i.e. cement and fly ash

*2.2 Testing methods*

(1) The forming process of the specimen: cement, fly ash, quartz sand and air entraining agent were well weighed, stirred for 2min in the mixer and adding water stirred for 3min. Then PVA fiber was added, continuing to stir for 5min at high speed to uniform, demolded after pouring in 24h. Curing conditions: (20 + 2) oC, humidity of 95%, curing age of 7d, 28d, 90d.

(2) The axial tensile: the specimen was dumbbell-shaped and the thickness was 13mm. The axial load was measured by a 10kN sensor. The axial deformation was measured by an electronic extensometer with the maximum deformation amount of 10% and the loading speed was 0.1mm/min. The size of specimen is shown in Figure. 1.

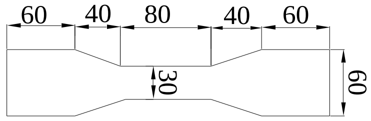
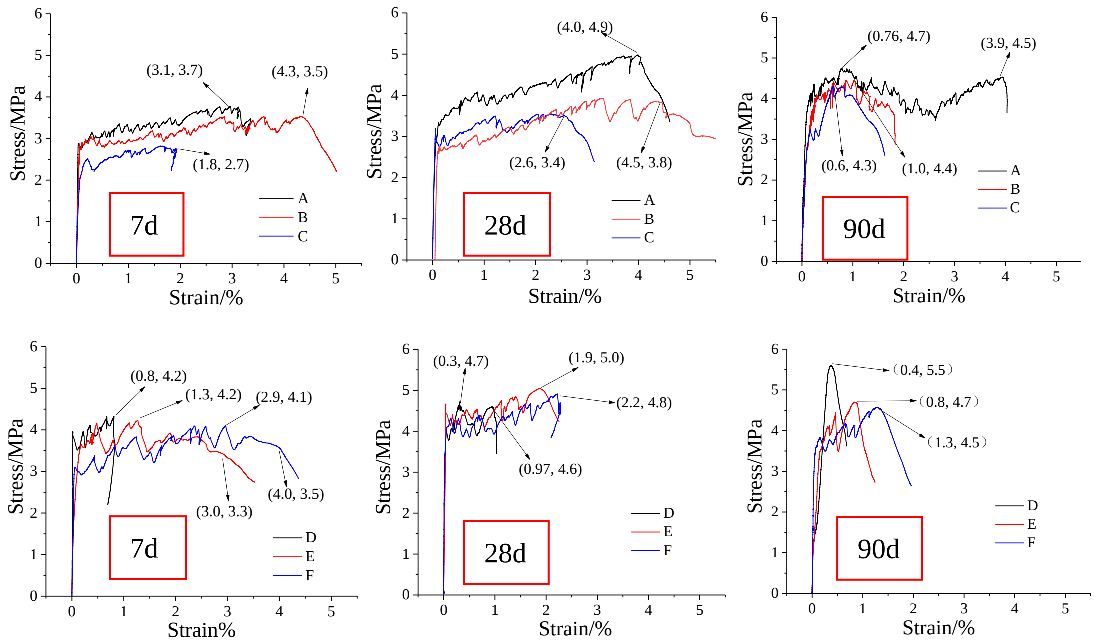



**Figure 1.** Uniaxial tensile specimen size

## 3. Experimental results and Discussion

The tensile stress-strain curve of the specimen at different ages is shown in Figure. 2. It can be seen from the specimens A, B and C with fly ash that the tensile stress fluctuation is small and the crack distribution of the specimen is fine. The uniaxial tensile strength decreases with the increase of the amount of air entraining agent. Compared with the specimen A, the tensile strain of the specimen B with air entraining agent content of 0.05% increases. The tensile strain of the specimen C decreases with air entraining agent of 0.1%. At 7d, 28d and 90d, the stresses of B decrease by 5%, 22% and 21%, and the strains increase by 39%, 12.5% and 33%, respectively. The stresses of C decrease by 31%, 31% and 18%, and the strains decrease by 42%, 35% and 35%, respectively. It can be seen from D, E and F that there is no fly ash in the cementitious material with the sand / cement of 0.36. At 7d and 28d, the tensile stress of the specimen with air entraining agent is almost unchanged, and the tensile stress reduces by 18% at 90 d. The tensile strain increases with the increase of the amount of air entraining agent. At 7d, 28d and 90d, the tensile strains of E increase by 2.7, 0.96, 1 time, respectively. The tensile strains of F increase by 4, 1.3 and 2.7 times, respectively. From G, H and I, it can be seen that when the cementing material does not contain fly ash with sand / cement of 0.51, the tensile stress decreases and the tensile strain increases with the increase of air entraining agent content. At 7d, 28d and 90d, the tensile stresses of I decrease by 29.8%, 6.5%, 33.9, respectively, and the tensile strains increase by 1.9, 3 and 2.1 times respectively.

The reasons of the results above: When a large amount of fly ash is added, the inert fine particles of fly ash adhered to the surface of the fiber to form a layer of film ball, avoiding the direct contact of fiber and matrix of hydration products, reducing the effect of matrix to fiber the chemical bond. Additionally, The resultants of fly ash reacting with cement hydration products are spherical particles with dense smooth surface, which can play ball bearing lubrication. Therefore, the tensile strain hardening phenomenon is obvious. When there is no fly ash in cementitious material, the bond force between fiber and matrix is large, and the fiber is broken when pulling out from the matrix. The bridging effect of fiber is not fully functional, and the tensile stress fluctuates greatly. When air entraining agent is mixed into mortar, a large number of uniform and stable micro bubbles are introduced to reduce the contact area between fiber and mortar matrix, thus reducing the bond force between fiber and matrix. Under tensile load, the fiber cannot break, but the bonding force between the fiber and the matrix would be overcome when the fiber is pulled out, which is greater than the cracking stress of the matrix. The fiber plays a bridging effect, the tensile strain increases to produce strain hardening.



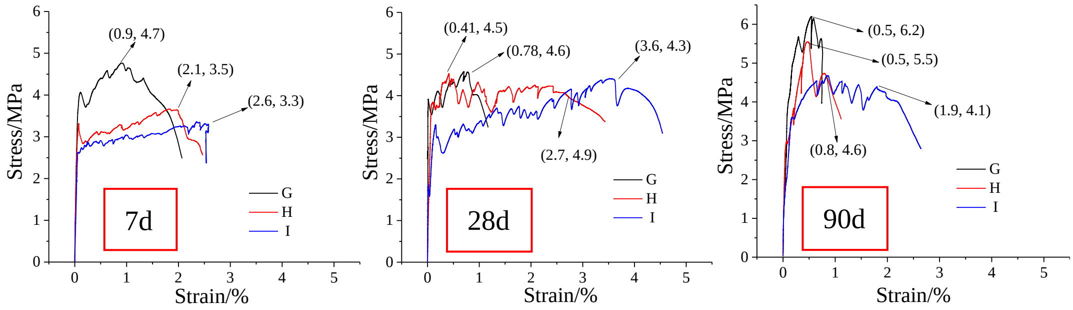



**Figure 2.** Tensile stress-strain curves at different ages

## 4. Conclusions

(1) The uniaxial tensile strength decreases with the increase of the amount of air entraining agent.

(2) When the amount of fly ash is higher and a large amount of air entraining agent are added, the tensile strain reduces. When there is no fly ash in the cementitious material, the tensile strain increases with the incorporation of air entraining agent.

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