Effect of different fibers on mechanical properties and ductility of alkali-activated slag cementitious material

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Effect of different fibers on mechanical properties and ductility of alkali-activated slag cementitious material

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Abstract. The effect of different fibers on mechanical properties and ductility of alkali-activated slag cementitious material (AASCM) is studied. The research contents include: fiber type (plant fiber, polypropylene fiber), fiber content, mechanical property index, tensile stress-strain relationship curve, treating time. The test results showed that the compressive strength of two fibers reinforced AASCM was about 90 ~ 110MPa, and the tensile strength was about 3 ~ 5MPa. The reinforcement effect of polypropylene fiber is superior to that of plant fiber, and the mechanical properties of polypropylene fiber reinforced AASCM are superior to those of plant fiber. According to the comparison of SEM pictures, the plant fiber and polypropylene fiber are both closely bound with the matrix, and the transition zones are complete and close. Thus, it is proved that plant fiber and polypropylene fiber delay the crack extension and enhance the ductility of AASCM.

1. Introduction
Alkali-activated slag cementitious material (AASCM) is a type of cementitious material through the chemical reaction obtaining [1-3], with slag and alkaline activators such as sodium silicate, NaOH as the main raw materials, with or without a certain cold heat history of aluminate natural minerals containing silicon or industrial waste residue (e.g metakaolin, phosphorus slag, steel slag, coal gangue, fly ash, red mud, etc) and alkaline activators (such as alkali metal hydroxide, alkali metal carbonate, alkali metal sulfate, etc). It uses industrial waste slag as the raw material and has the advantage of high temperature resistance, corrosion resistance, energy conservation and environmental protection, and has aroused the wide concern of scholars both at home and abroad [4-8]. Since the 1980s in China, AASCM has begun to be studied and also made a lot of research results [9, 10]. AASCM has excellent compressive properties, heavy metal ion solidification, and thermostability [11], but AASCM belongs to brittle material, so its tensile properties are relatively low. To overcome the brittleness of AASCM, Li [12] studies steel fiber reinforced alkali-activated slag panels, witch has good reinforced effect. This essay used plant fiber and polypropylene fiber (PPF) in increasing the ductility of AASCM.
2. Materials and Formulation

2.1. Raw materials and mix proportion
S95 slag is proposed by mass fraction of 36.9% SiO$_2$, mass fraction of 15.66% Al$_2$O$_3$, mass fraction of 37.57% CaO, mass fraction of 9.3% MgO, mass fraction of 0.36% Fe$_2$O$_3$. The activity indexes of slag are mainly: the quality coefficient 1.69, the alkaline coefficient 0.97, and the activity coefficient 0.42. The main parameters of potassium silicate solution are shown in table 1. The mass fraction of sodium hydroxide is not less than 96.0%.

| Baume degree | Density (g/mL) | Modulus | mass fraction, % |
|--------------|----------------|---------|-----------------|
| 46.3         | 1.465          | 2.76    | 15.98, 28.15    |

*Note: Baume degree for potassium silicate is the unit of density for liquids measured by hydrometer.

Test uses two relatively optimal W32, W35 of AASCM and main parameters are shown in table 2.

| Number | Slag | Modulus of potassium silicate | potassium silicate amount, % | Sodium hydroxide amount, % | Water amount, % |
|--------|------|-------------------------------|------------------------------|----------------------------|----------------|
| W32    | 1    | 1.0                           | 14                           | 4.58                       | 32             |
| W35    | 1    | 1.0                           | 12                           | 5.35                       | 35             |

The plant fiber and PPF were selected for the test fiber type, and wheat straw is chosen as plant fiber. Its length is 2 cm ~ 3 cm. To improve the moisture content of wheat straw and the mechanical interaction of wheat straw and matrix, the wheat straws were treated by mass fraction of 10% sodium hydroxide solution to soak for 20, 60 min, then soaked in clean water for 2 min. After wheat straws were placed in the shade to dry, the final moisture content of wheat straws was controlled about 15%. In addition, the length of PPF is 1 cm ~ 2 cm and its elastic modulus is 42GPa. The fiber pictures are shown in figure 1.

![Fiber pictures](image)

2.2. Production and maintenance of specimens
The samples were prepared by mixing raw materials--slag and alkaline activators in a 5 liter pan mixer. The sequence of mixing was important to homogenize the fresh paste. Thus, the raw materials were firstly mixed for about 30 s, the alkaline activators and water were then poured into the pan, and stirred at low speed for approximately 6 min until the mixture was glossy and well combined. Then, the plant fibers (The percentage of plant fiber is 1%) or polypropylene fibers (The percentage of polypropylene fibers is 0.7% and 1%) were mixed and stirred for approximately 1 min. The fresh paste was cast in various shapes of moulds for measurement of strength. They were maintained in a humidistat at 20 ± 2°C and 95% relative humidity. The samples were demolded after 24 h of humidity.
maintaining and then stored in a humidistat at 20 ± 2℃ and 50% relative humidity until testing commenced.

3. The strength varies with age

3.1. Compressive strength of cementing materials

Figure 2 shows compressive strength of cementing materials of two fibers reinforced AASCM with the age.

By comparison, the compressive strength of two fibers reinforced AASCM was 90~105MPa, which are better than AASCM matrix. After observing the failure of the specimen, it is found that plant fiber and polypropylene fiber not only improve the ductility of AASCM, but also improve compressive strength of AASCM. The reason is that the wheat stalk and PPF are small and tightly coupled with the matrix, which can be distributed evenly in AASCM to achieve enhanced mechanical properties. The incorporation of straw and PPF can obviously delay the crack extension and enhance the ductility of AASCM. Thus, the enhancement of PPF to AASCM is better than that of plant fiber.

![Figure 2. Compressive strength of cementing materials](image)

3.2. Axial tensile strength

The axial tensile strengths of the two kinds of fibers reinforced AASCM are shown in figure 3.

![Figure 3. Effect of different fibers on Axial tensile strength of dumbbell type specimen](image)

It can be seen from figure 3 that the development of tensile strength of AASCM is similar to compressive strength and flexural strength, which increase with the increase of age. The axial tensile strength of W32 specimen is maximum. The 28d AASCM flexural strength is about 1/10 of compressive strength of cementing materials, and axis tensile strength is about 1/40 of compressive
strength of cementing materials, and the tensile strength of PPF reinforced AASCM is superior than that of plant fiber reinforced AASCM.

The axial tensile strength reflects the enhancement of the ductility of AASCM, which shows that the fundamental reason for the change of the macroscopic mechanical properties of fibers reinforced AASCM is that the fiber makes the AASCM microstructure more compact, and the tensile effect of fibers enhance the toughness of the AASCM matrix.

3.3. Comparison of tensile stress-strain relationship curve

The comparison of tensile stress-strain relationship curve is shown in figure 4. The percentage of plant fiber is 1%, and the percentage of polypropylene fibers is 0.7%. According to the figure, it can be seen that with the addition of two kinds of fibers, the area under the tensile stress and strain curve increases, which indicates that the ductility and toughness of the fibers reinforced AASCM are better than matrix. The PPF is superior than plant fiber on improving the ductility of AASCM.

![Figure 4. tensile stress-strain relationship curve](image)

When the AASCM is not reinforced with plant fiber, the descending curve of AASCM matrix is very steeper, which indicates that the failure process is rapid and the brittleness of AASCM is obvious. When the AASCM is reinforced with plant fiber, the descending curve is flatter and longer, which indicates that the plastic deformation capacity of AASCM has improved. When the AASCM is reinforced with PPF, the descending curve is the flattest and longest, which indicates that the plastic deformation capacity of PPF reinforced AASCM has further improved, and the PPF is superior than plant fiber on improving the ductility of AASCM, just as mentioned in 3.1 and 3.2.
4. Compressive strength of different fibers reinforced AASCM block

The comprehensive strengths of different fibers reinforced AASCM block are shown in figure 5, figure 6 and figure 7. The percentage of plant fiber is 1%, and the percentage of polypropylene fibers is 0.7%. The fracture forms of the single row of holes block compressive strength, single-hole block compressive strength and standard solid brick compressive strength are carefully analyzed.

The test results showed that the compressive strength of single row of holes block of matrix AASCM is equivalent to that of MU10 (\textit{MU} means masonry unit, and 10 means the compression strength of block is 10MPa) concrete block. Moreover, the compressive strength of standard solid brick of matrix AASCM is in the middle of that of MU20 and MU25 concrete block. Which basically meet engineering requirements. In addition, the compressive strength of the PPF reinforced AASCM is highest, and that of plant fiber reinforced AASCM is better, then that of matrix is lowest.

The research contents include: fiber type: plant fiber, polypropylene fiber; mechanical index: single row of holes block compressive strength, single-hole block compressive strength and standard solid brick compressive strength. The vertical cracks are crushed at the corners. Compared with the matrix, the plant fiber and PPF have good tensile properties because of those high fiber strength. Thus the fibers reinforced AASCM have ideal ductility.

![Figure 5](image1)

\textbf{Figure 5} Compressive strength of single-row hole block

![Figure 6](image2)

\textbf{Figure 6} Compressive strength of single-hole block

![Figure 7](image3)

\textbf{Figure 7} Compressive strength of solid brick

5. SEM analysis

The different fibers reinforced AASCM are analyzed by SEM, and the SEM pictures are shown in figure 8. According to SEM pictures of figure 8, it can be seen that the plant fiber and PPF are both
closely bound with the matrix, and the transition zones are complete and close. Thus, it is further
proved that plant fiber and PPF can delay the crack extension and enhance the ductility of AASCM.

Figure 8. SEM pictures of fibers reinforced AASCM

According to scanning electron microscopy (SEM) test, it can be seen a series of changes; the
combined with plant fiber had good biocompatibility, interface morphology complete. Polypropylene
fiber and plant fiber are different degree intensifies the material internal structure defects. Thus,
Microstructural changes revealed the root of changes in the macro mechanical properties.

6. Conclusions
(1) Test proves that plant fiber and PPF reinforced AASCM have excellent mechanical properties and
these two kinds of fibers can improve the mechanical properties and enhance the ductility of AASCM
matrix. Compared with the matrix, the plant fiber and PPF have good tensile properties because of
those high fiber strength.
(2) The compressive strength of the PPF reinforced AASCM is highest, and that of plant fiber
reinforced AASCM is better, then that of matrix is lowest. The compressive damage of the AASCM
block is similar to that of the concrete, and the vertical cracks are crushed at the corners. Single row of
holes block compressive strength, single-hole block compressive strength and standard solid brick
compressive strength basically meet engineering requirements.
(3) According to SEM pictures, the plant fiber and PPF are both closely bound with the matrix, and the
transition zones are complete and close, which can delay the crack extension and enhance the ductility
of AASCM. Polypropylene fiber and plant fiber are different degree intensifies the material internal
structure defects.

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