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LONG-TERM MECHANICAL BEHAVIOR OF A GREEN CEMENTITIOUS COMPOSITE

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In this paper, a new green hybrid bagasse fiber (3% by volume) and steel fiber (0.7% by volume) reinforced cementitious composites with high volume fly ash (fly ash to cement ratio of 1.6) is developed and cured in weather condition up to 10 months. Basic mechanical tests, such as compressive test, Young's modulus test, flexural test, and uniaxial tensile test and SEM tests were conducted at the age of 28 days, 3 months, 6 months and 10 months, respectively. Through comparison with the mechanical behavior of the composite at the age of 28 days, the long-term effect on the mechanical properties of the composite is evaluated. It is found the mechanical properties of the new composite increases greatly with aging. At the age of 10 months, the composite becomes more compacted and the composite is of excellent mechanical properties making it very promising to be used as commercial building materials.

Keywords: Bagasse fiber, Cementitious materials, Fly ash, Mechanical behavior, Steel fiber.

1 INTRODUCTION

Natural fibers could be used to enhance the mechanical behavior of the cementitious composites. However, the natural fiber-reinforced cement-based matrix shows weak points over long term. The primary concern is the durability of natural fibers in the alkaline environment of cement. Natural fibers suffer from degradation in the cementitious alkali media, and presents decreasing mechanical properties (Marikunte *et al.* 1994, Toledo Filho *et al.* 2003). The main reason for the degradation of mechanical properties of the natural fibers lies in the alkali media and the hydration reaction of the cementitious matrix, which dissolves the amorphous materials of natural fibers (Gram, 1983, Sedan *et al.* 2007) and reduces the tensile strength of natural fibers (Sedan *et al.* 2007, Wei *et al.* 2014).

Experimental study found that surface modified natural fibers could improve the long-term mechanical properties of fiber reinforced cementitious composites. Surface modification, such as chemi-thermomechanical pulping, heat treatment, and fiber coating could effective improve the mechanical properties of cementitious composites when the composite specimens were subjected to long-term weathering or accelerated aging condition (Abdelmouleh *et al*. 2005, Castellano *et al.* 2004, Savastano *et al.* 2001, 2003, 2005). Bagasse fiber, which is the by-product of the cane sugar industry, has been found to be able to improve the basic mechanical properties of the cementitious composites, but the long-term mechanical behavior of the composites with modified bagasse fiber are not known yet.

Using additives to partially replace cement could also improve the mechanical properties of natural fiber reinforced cementitious composites Savastano *et al.* (2001, 2003, 2005). As a by-product of coal fired power station, fly ash has been proved to be an effective pozzolanic material that could be used together with cement as a component of concrete matrix. Experimental studies found that fiber reinforced cementitious composite containing high volume fraction of fly ash could exhibit outstanding short and long term mechanical behavior with reduced material cost. However, the influence of bagasse fiber and fly ash on the mechanical behavior when they are used together is of uncertainty. The long-term mechanical properties of bagasse fiber reinforced cementitious composites with high volume fly ash need to be investigated.

In this paper, the long-term mechanical properties of a green hybrid bagasse fiber (3% volume of fraction) and steel fiber (0.7% volume of fraction) reinforced cementitious composite with high volume fly ash were tested to obtain compressive strength, Young's modulus, flexural behavior and uniaxial tensile behavior when the composites specimens were placed under natural weathering condition for 28 days, 3 months, 6 months and 10 months, respectively. The long-term effect on the mechanical properties of the composite is evaluated.

2 A GREEN FIBRE REINFORCED CEMENTITIOUS COMPOSITE

A green fiber reinforced cementitious composite with cement, fly ash, sand, water, reduce agent, bagasse fiber and steel fiber was developed. The content of steel fiber and bagasse fiber are 0.7% and 3% by volume, respectively. The mix design of the composites is listed in Table 1. Bagasse fibers were treated with surface modification firstly and then added into the matrix (Tian and Zhang 2013, 2014, 2014a).

Table 1. Mix design of the composite.

Cement [kg/m^3]	**Fly ash [kg/m^3]**	**Sand [kg/m^3]**	**Water [kg/m^3]**	**Reduce agent [kg/m^3]**
487.78	780.45	439	329	6.34

Compressive specimens are cubes of 50 mm × 50 mm × 50 mm for the compressive strength testing. The Young's modulus of the composite was tested using cylinders of 200 mm in length and 100 mm in diameter. Four-point bending test was employed to measure the flexural properties of the composite specimens with dimensions of 350 × 100 × 100 mm. The set-up for the compressive strength, Young's modulus and the flexural test could be found in Figure 1. The tensile behavior of the composite was measured by conducting uniaxial tensile tests on the dog-bone shaped specimens. The dimension of the dog bone shaped specimen and the set-up of the tensile test are shown in Figure 3. For all the mechanical tests, 3 specimens were prepared and tested. All the composite specimens were cured in the weathering condition for up to 10 months and tested at the age of 28 days, 3 months, 6 months and 10 months.

(a) Compressive test. (b) Young's modulus test. (c) Flexural test.

Figure 1. Basic mechanical property tests.

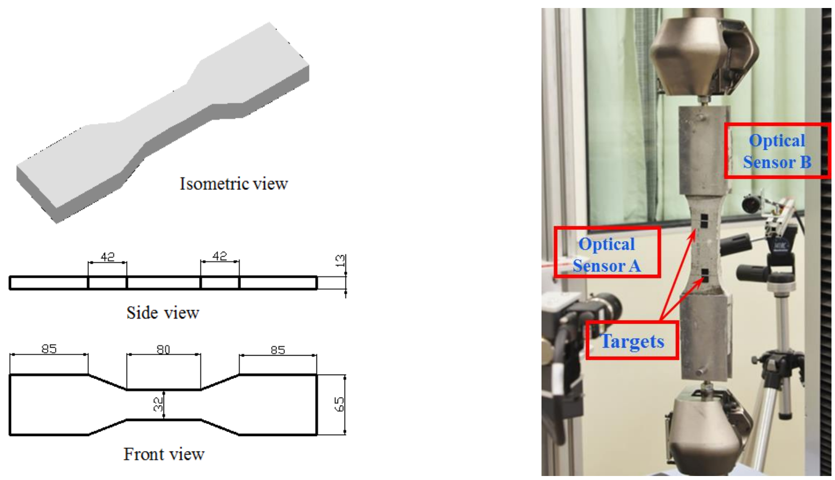


Figure 2. The dog-bone specimen and tensile test set up.

3 RESULTS AND DISCUSSIONS

The compressive strength and the Young's modulus of the composite at the age of 28 days, 3 months, 6 months and 10 months are listed in Table 2.

Table 2. Compressive strength and Young's modulus of the composite at different ages.

Curing time	28 days	3 months	6 months	10 months
Compressive strength (MPa)	36.67	44.56	50.61	59.37
Young's modulus (GPa)	15.15	23.16	24.28	26.07

As can be seen from Table 2, the compressive strength of the composite increases greatly with time. When the age of the composite increases from 28 days to 3 months, 6 months and 10 months, the compressive strength of the composite increases from 36.67 MPa to 44.56 MPa, 50.61 MPa and 59.37 MPa, respectively, which increases by 21.5%, 38%, and 61.9% comparing with the compressive strength of the composite at the age of 28 days. The Young's modulus of the composite also shows an increasing trend. At the age of 28 days, the Young's modulus of the composite is 15.15 GPa. As the age increases to 3 months, 6 months and 10 months, the Young's modulus of the composite increases to 23.16 GPa, 24.28 GPa, and 26.07 GPa. This increase in the Young's modulus and the compressive strength of the composite is the result of continuous hydration effect of cementitious material with time, which leads to the increase in the compactness of the composite.

The modulus of rupture (MOR) and the toughness of the composite at different ages are shown in Table 3, and the flexural behavior of the composite at different ages is presented in Figure 4.

Table 3. Modulus of rupture and toughness of the composite at different ages.

Curing time	28 days	3 months	6 months	10 months
Modulus of rupture (MPa)	5.34	5.79	6.78	6.79
Toughness (kJ/m^2)	1.97	3.85	6.54	7.12

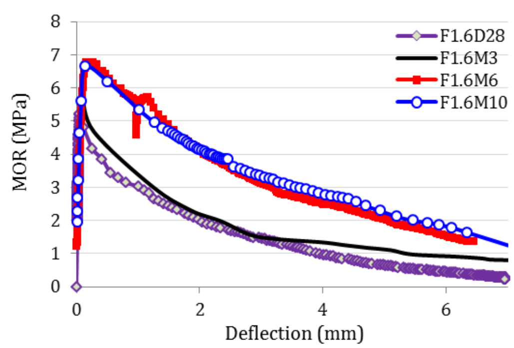


Figure 3. Flexural behavior of the composite at different ages.

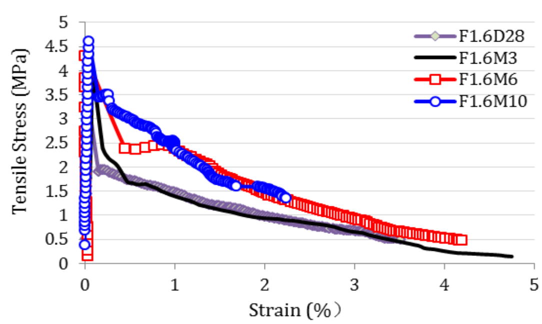
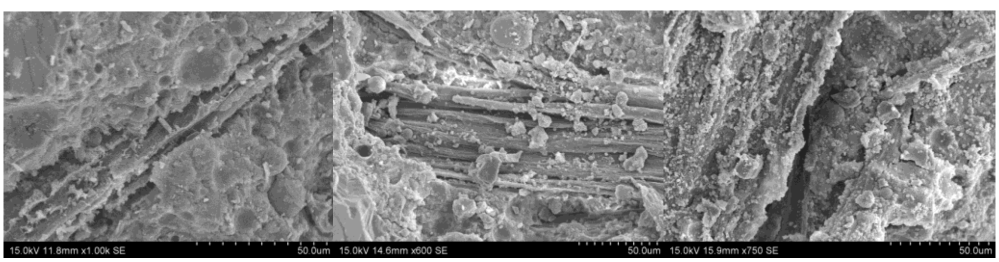


Figure 4. Uniaxial tensile behavior of the composite at different ages.

It could be observed from Figure 3 that both the MOR and the toughness of the composite increases gradually as the composite specimen grow from 28 days to 3 months. During this period, the MOR of the composite increases from 5.34 MPa to 5.79 MPa, and the toughness of the composite ascends from 1.97 kJ/m^2 to 3.85 kJ/m^2. After this, both the MOR and the toughness of the composite undergo a dramatic increase as aging, reaching 6.78 MPa and 6.54 kJ/m^2 at 6 months, and then remains around this level until the composite was cured for 10 months.

The uniaxial tensile behavior of the composite at the age of 28 days, 3 months, 6 months, and 10 months is compared in Figure 4. For the composite with fly ash to cement ratio of 1.6, when the age of the composite increases from 28 days to 3 months, 6 months and 10 months, its tensile strength increases smoothly from 3.4 MPa to 4.2 MPa, 4.31 MPa and 4.6 MPa. In the term of ductility, the composite of 3 months old shows similar ductility as the composite of 28 days old. When cracks happen, the tensile stress drops immediately to below 2 MPa and declines continually until the final damage. However, when the composite becomes 6 months old, the ductility of the composite increases suddenly and a strain-hardening behavior could be observed. At the age of 10 months, the tensile stress drops to around 3.5 MPa when crack happens. After a little strain-hardening stage, the tensile stress declines gradually, presenting almost the same residual tensile stress as the tensile behavior at the age of 6 months after the strain reached 1%.

The microstructure of the composite is also studied using scanning electron microscope (SEM). The fracture specimen from the tensile tests is subjected to the SEM test at the age of 28 days, 3 months, 6 months, and 10 months.



(a) 3 months. (b) 6 months. (c) 10 months.

Figure 5. The microstructure of the composite at different ages.

Figure 5 shows the interspace of the composite at the age of 3 months, 6 months and 10 months, respectively. As the increase of the age, the space and the voids between the fiber and the matrix are replaced with hydration product gradually. Fly ash particles could be observed in the interspace zone between bagasse fiber and the matrix, showing the filling role of fly ash in the composite which may lead to the increase of the long-term tensile behavior. From Figure 3, it could be found that the fiber surface and inner tube are embraced with a layer of hydration product and small fly ash particles. All these alkali material may reduce the toughness of bagasse fiber and decrease the mechanical behavior of the composites accordingly after long-term curing condition.

4 CONCLUSIONS

A new green hybrid bagasse fiber and steel fiber reinforced cementitious composites with high volume fly ash were developed in this paper. Basic mechanical tests, such as compressive test, Young's modulus test, flexural test, and uniaxial tensile test and SEM tests at the age of 28 days, 3 months, 6 months and 10 months were tested and evaluated. The compressive strength, Young's modulus, modulus of rupture and tensile strength of the green cementitious composite increase greatly with aging. The ductility such as the toughness and the tensile ductility of the composite also increase dramatically with aging.

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