Compressive Creep of PVA-ECC Material at Early Age

Yichai Huang*, Yufei Liang[a], Yufei Liang[b], Zixiang Gong[c]
SWJTU-LEEDS JOINT SCHOOL, Southwest Jiaotong University, Chengdu 610031, China,
*Corresponding author email: cn22y2h@leeds.ac.uk
[a]cn223yl@leeds.ac.uk
[b]cn22y3l@leeds.ac.uk
[c]cn22z2g@leeds.ac.uk

Abstract. The creep behaviors of prepared PVA-ECC materials(fiber content 1.5%) and normal concrete were tested through stress creep test at a stress level of 35%, along with a shrinkage test during early age(0-28d). Results indicate that PVA-ECC material exhibits lower shrinkage and a creep coefficient 1.45 times higher than that of normal concrete with the same strength at early age.

Keywords: PVA-ECC; Creep; Shrinkage; DPDM.

1. Introduction

Recent advancements in engineered cementitious composites, particularly those incorporating polyvinyl alcohol fiber (PVA-ECC), have attracted significant attention in the engineering community[1-3].

The creep, which is the property of strain increase with time under continuous stress[4], is especially prominent in early-age concrete. It significantly mitigate the effects of thermal stress and shrinkage-induced cracking, and leads to prestress loss in prestressed concrete structures. This results in increased deformation of the structural members and induces stress redistribution[5-6]. Most existing research on PVA-ECC has focused on its short and medium-term properties. In addition, traditional concrete creep measurement methods are prone to large errors due to unstable contact with the specimen. This paper compares the compressive creep of normal concrete (30MPa) with that of PVA-ECC during 28d, which can provide data for the use of PVA-ECC in areas such as bridge decks and new green building fields.

2. Experiment

2.1 Experimental materials and mixing ratio

This experiment refers to GB/T50082-2009 “Standard for test methods of long-term performance and durability of normal concrete”. Since the material does not contain coarse aggregate, the compressive specimens were determined to be cubes of $100mm \times 100mm \times 100mm$, the creep specimens were determined to be cubes of $100mm \times 100mm \times 300mm$, and the shrinkage specimens were determined to be cubes of $150mm \times 150mm \times 300mm$. Two PVA-ECC specimens and normal concrete specimens were taken from the same batch for each experiment set. The mixing ratio is m(cement): m(coal ash): m(silica fume): m(water reducing agent): m(water) =76.5: 95.5: 12.7: 2.3: 50.3. A PVA fiber with 1.5% of doping calling KURALON K-11 is produced by Kuraray Company in Japan. The performance parameters are listed in Table 1.

Table 1. Properties of PVA Fiber

Tensile Strength (MPa)	Length (mm)	Diameter (um)	Density (g/cm3)	Elongation (%)	Elastic Modulus (cN/dtex)
1500	12	40	1.3	6	350

2.2 Experimental methods and equipment

After casting, the specimens were placed in a curing room with RH>90%. 24h later, they were relocated to a laboratory with RH=60% and mounted on a creep test device.

To roughly obtain strain data, micrometers were installed on all four sides of the prismatic concrete specimens to monitor their vertical displacement. Concurrently, compressive strength specimens and shrinkage specimens were also prepared to determine the test load magnitude and measure concrete shrinkage respectively. Given the laboratory's loading stress level and the nonlinearity of creep, the stress level for this experiment was set at 35%. Therefore, the creep loading scheme involved loading the specimens during 28d of age with a stress level of 35%—that is, applying a stress equivalent to 35% of the compressive strength measured during the same period, which remained unchanged after 28d.

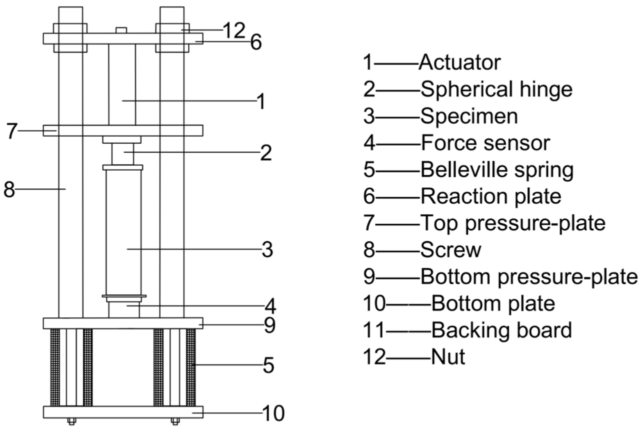

Fig. 1. Creep meter

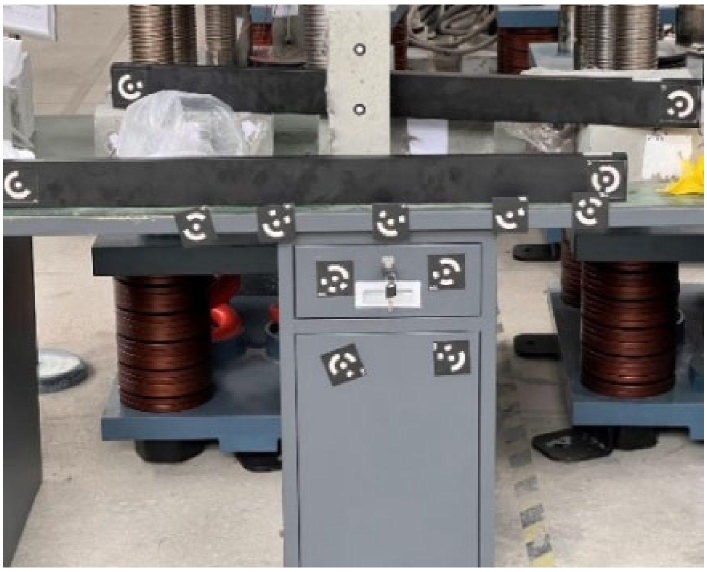

Fig. 2. DPDM

In this experiment, the creep strain is measured by Digital Photogrammetry for Deformation Measurement (DPDM). This experimental setup integrates close-up digital photography with image processing analysis. In digital photography, cameras equipped with high-resolution sensors and precise optics capture surface images of the concrete structure. These images are saved in a high-resolution digital format, providing measurements more accurate than the micrometer method.

3. Results

3.1 Compressive Strength

Based on GB/T 50081-2002 "Standard for test method of mechanical properties on normal concrete", the compressive strength tests of PVA-ECC material and NC were conducted using a cube of $100mm \times 100mm \times 100mm$. The measured compressive strengths of PVA-ECC and NC specimens at the ages of 3,7,14 and 28d are shown in Table 2.

Table 2. Compressive Strength at early-age

Age/d	PVA-ECC(MPa)	NC(MPa)
3	20.5	21.2
7	24.8	26.5
14	29.6	29.7
28	35.8	31.1

As can be seen from table 2, 28d strength of NC was 31.1 MPa, slightly higher than 30 MPa. PVA-ECC's strength was initially slightly lower than NC's but exceeded it at 28d. After 28d, the voids and micro-cracks of NC were filled with hydration products, limiting strength growth. In contrast, PVA fibers' combination with the cement matrix strengthened over time, limiting crack expansion. It also enables a rapid increase in compressive strength of PVA-ECC and a higher integrity of specimen under pressure.

3.2 Properties of shrinkage

The shrinkage test results for NC and PVA-ECC materials are shown in Fig 3

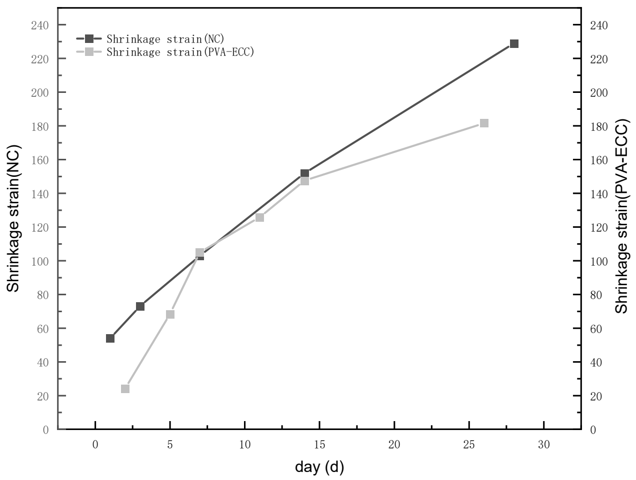

Fig. 3. Shrinkage test results

As seen in Figure 3, The shrinkage of NC is the same with PVA-ECC at 5~10d after casting, and greater than PVA-ECC at all other stages. The hydration reaction process of NC at early age may lead to more water dissipation and greater shrinkage. PVA-ECC contains more coal ash that can reduce the rate of exothermic heat release.

3.3 Properties of creep

The creep deformation accumulates over time and its development rate is high. Figure 4 illustrates the creep development curve of NC and PVA-ECC material. It can be observed that there is a rapid increase in creep during the early age of 1-14d, followed by a gradual slowdown after 14d. Additionally, the creep deformation of PVA-ECC material is significantly larger than NC.

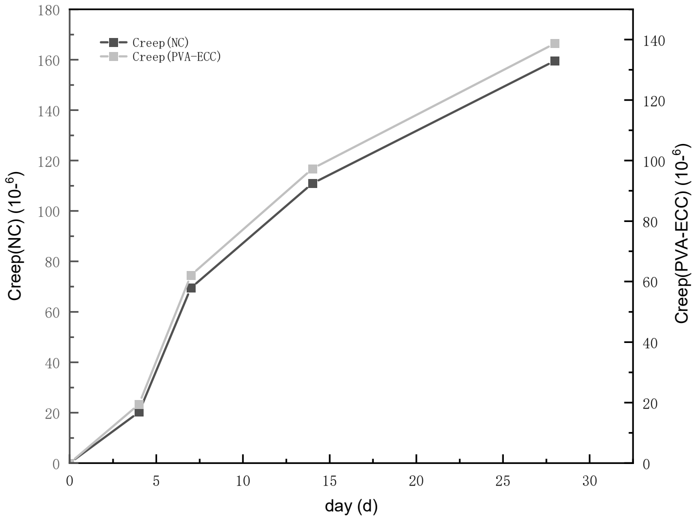

Fig. 4. Creep test results

The final value of creep strain ε_{PVA} and ε_{NC} for at each stage are listed in Table 3. It can be seen that the ultimate value of the creep strain of PVA-ECC is about 1.14 times that of NC under the same stress level during the early-age.

Table 3. Final value of creep strain at each loading program $\times 10^{-6} m/m$

Loading time/d	ε_{PVA}	ε_{NC}	$\frac{\varepsilon_{PVA}}{\varepsilon_{NC}}$ /%
1-4	20.238	19.460	104
4-7	69.523	62.074	112
7-14	110.952	97.326	114
14-28	159.524	138.717	115

With JTG D62-2012 ‘Code for-Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts’, the creep coefficients of NC and PVA-ECC at each stage are calculated and depicted in Fig. 5. It is obvious that the creep coefficients of the materials developed faster at the early age. However, regardless of age, the creep coefficient of PVA-ECC is significantly larger than that of NC. The creep coefficient of NC is approximately 69% of that of PVA-ECC. This is the same as the result of the long-term creep test study of PVA-ECC material in literature 9 and 10.

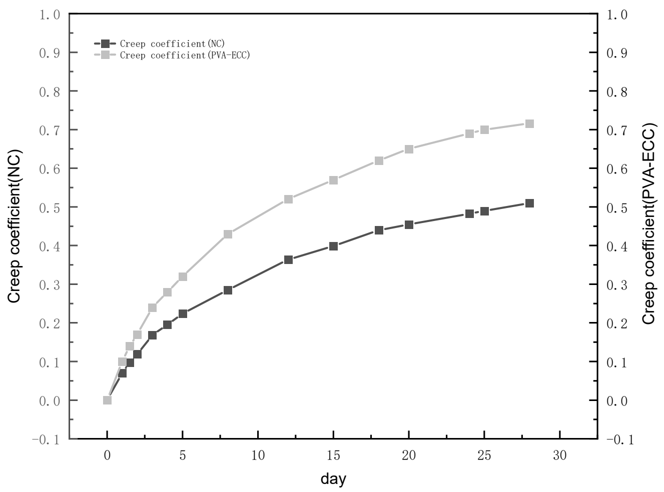

Fig. 5. Creep Coefficient results

4. Conclusion

(1) The total shrinkage of PVA-ECC(fiber content 1.5%) during early age (28d) is slightly lower than that of normal concrete with equivalent strength, but the amount of shrinkage is the same at its 5~10d.

(2) The creep coefficient of PVA-ECC is about 1.45 times of that of normal concrete, and the final creep strain value of PVA-ECC during early age is about 1.14 times of that of normal concrete with the same strength.

(3) PVA-ECC material during the early age obtains a large creep deformation characteristic and can reduce the shrinkage cracking of the component. Through reasonable structural design and construction control, the outstanding performance of PVA-ECC can be fully utilized in high-rise buildings and bridge deck pavements, providing a solid guarantee for the safety and durability of the structures.

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