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Microstudy on creep of concrete at early age under biaxial compression

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Abstract

An interesting phenomena of crack restoration and increasing strength of concrete under biaxial compression creep were described in this paper. A small loading apparatus was prepared and a long work distance optical microscope with variable focus was used for studying the cracks. It was found from the micrographs that these cracks diminished under biaxial compression creep. There were increases in the strength of the creep specimens under the sustained biaxial compression load compared with the free companion ones. Multiaxial compression caused by the early temperature rise inside the mass concrete may strengthen the concrete and reduce the tensile cracks during and after temperature drop.

Keywords: Creep; Microcracking; Concrete; Crack detection; Hydration

1. Introduction and objective

Scientists have studied a lot about the microstructure of cement paste [1]. However, little has been done about the mortar structure change when concrete is under sustained loads.

The conventional optical microscope is restricted in studying the properties of the slice concrete for their short work distance as well as small magnification. The electron microscopes themselves require the dry specimens (Scan Electron Microscopes) or the small and thin slices (Transmission Electron Microscopes), which are not suitable for us to study the long-term changes of the cement hydration under multiaxial sustained load. In this paper, a long variable focus and high magnification optical microscope (QHS-2005C) is used in the experiment. The microscope lens can work 15 mm away from the specimen even at 1000 × magnification. The highest magnification is 4000 ×. So it is suitable for us to study the interior configuration deformation and the crack changes in the cement paste and mortar under multiaxial stresses.

2. Microstudy on concrete creep under the biaxial compression

2.1. General

The numerical computation programs for creep are mainly based on the uniaxial creep tests in the past [2,3]. The microstructure of the cement paste is the basis of the creep mechanism. There were many creep hypotheses but no agreement has been totally achieved until now. No direct relations are constructed between the micro-experiments and the macro-tests, though we have made great improvement in the creep model and the numerical calculations [4]. The biaxial apparatus in this paper provides the rigidity displacement load as shown in Fig. 1. The load frame is made of steel, the modulus of which is approximately 10 times that of concrete. With the help of the high magnification optical microscope (QHS-2005C), it is possible for us to observe the creep changes especially the crack deformation inside the mortar and those between the interfaces of the aggregates. The dimension of the concrete slice is 100 × 100 × 10 mm.

The formation and development of the cracks have a very important influence on the mechanical properties of concrete. People sometimes keep the idea that creep deformations will cause interior damage on the concrete. Damage comes from the increasing cracks from the point view of the macro behavior. So we focused our attention on the changes of the cracks in the whole loading process.

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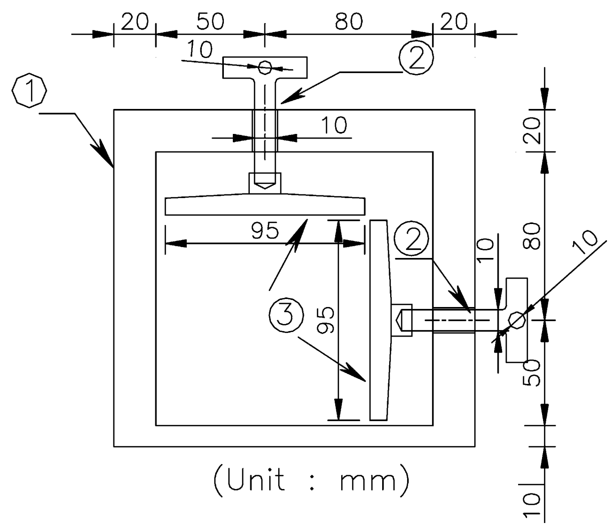

Fig. 1. Sketch plane figure of the loading apparatus. (1) Load frame; (2) Screw; (3) Load slab.

2.2. Introduction of the experiments

The specimen was a cube with the dimension of 100 mm. We cut it to slices of 10 mm thick at the age of 10 and 6 days, respectively. The mixture is listed in Table 1.

There were three groups of experiment. The specimens were loaded at the same day after slicing. We applied several rigid-displacement loads manually in case the loads were relaxed. The screw pushes the load slab forward and ensures biaxial load on the concrete slice. We added the load in one direction slowly then in another direction. Thus, the biaxial loads were increased alternately. The surface of the specimen was always kept wet.

2.3. Experiment results

2.3.1. Crack A

The first specimen was cut into slices at the age of 9 days and loaded at 10 days. Crack A originated as indicated by the arrow in Fig. 2 with about 44 μm long and 3–4 μm wide at the beginning. It was unloaded 14 days later.

(1) Crack A was very clear at the beginning of the loading (Fig. 3). It started from the bottom of an aggregate and then went around the edge of another aggregate. It ended by a third slim aggregate and truncated it. The surface

Table 1
Material mixture

Mixture (kg/m$_3$)	Water	Cement	Fly ash	Sand	Aggregate			Admixture	
					Small	Middle	Large	DH9	JG4
	78	60	100	673	465	620	465	3.2	4.8

DH9 and JG4 were the water reducer and the retarder, respectively.
The large and middle gravels were picked off after mixing.

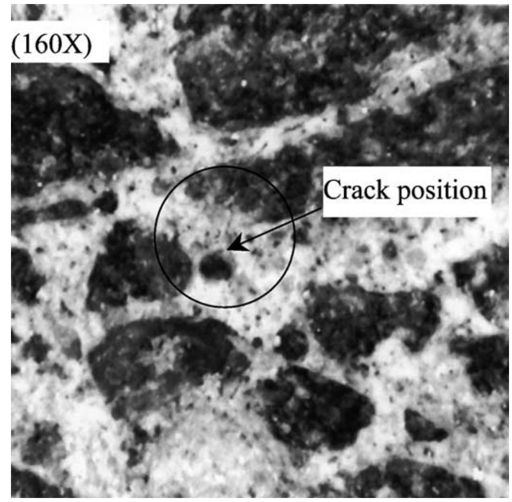

Fig. 2. Position of Crack A.

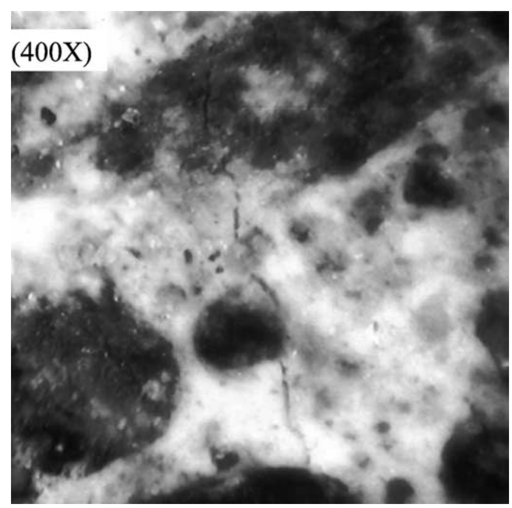

Fig. 3. Original crack loaded at the age of 10 days.

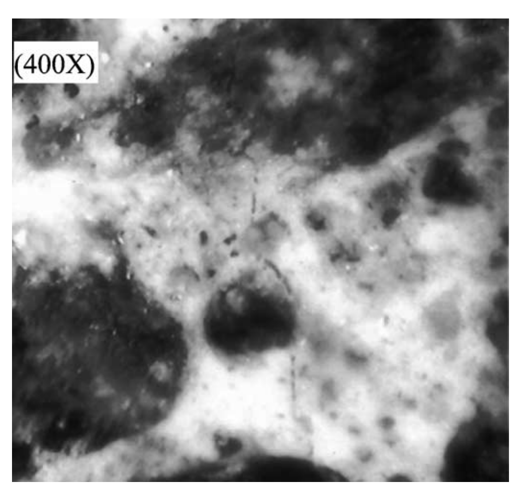

Fig. 4. Biaxial load for 6 h at the age of 10 days.

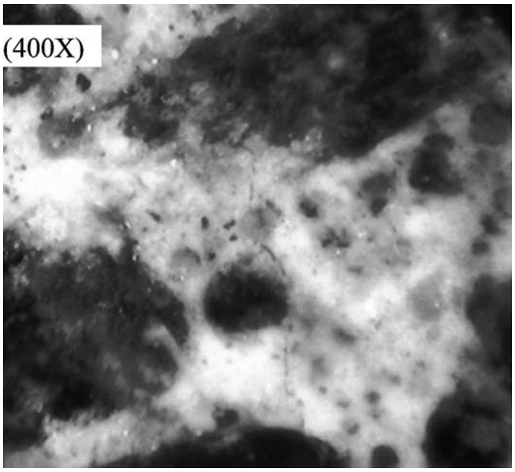

Fig. 5. Biaxial load for 24 h at the age of 10 days.

crack along the second aggregate was very clear. The part inside the mortar was also very distinct. It must be the outer load that created the crack for it ran across the whole slim aggregate.

(2) In Fig. 4, the crack was thinner than the one in Fig. 3 after the 6-h biaxial load. The width of the crack in the mortar diminished more than the crack around the edge of the aggregate, though both of them were still very clear.

(3) The crack continued to close up as the load held for 1 day (Fig. 5). However, the trail could still be observed. The interface crack around the aggregate did not close in the same degree.

(4) After 14 days, the crack diminished so much that the lower part of the crack could hardly be identified (Fig. 6). Only the upper one could still be observed. The middle part of it around the aggregate also closed more than before.

(5) The load was removed after 14 days. Six days later, the specimen was reloaded again. From Fig. 7, we can find that the crack did not open again. In fact, we could not

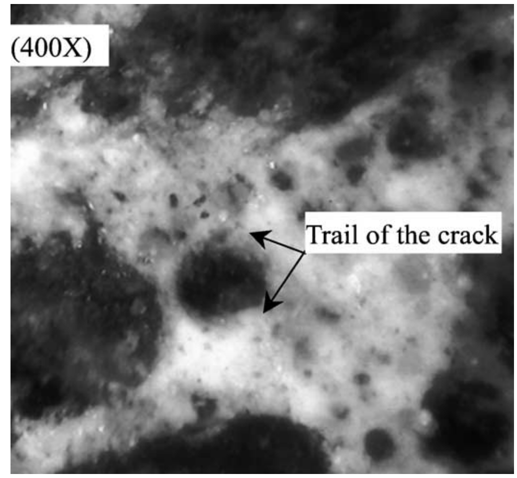

Fig. 7. Biaxial load for 14 days then unloaded for 6 days. Reload no cracks.

identify the former crack. Those cracks in the mortar disappeared entirely from the surface.

2.3.2. Crack B

The second specimen was sawn to slices at the age of 6 days. It was loaded at the same day and was held for 100 days. Two cracks, B-1 and B-2, were studied with the original dimensions by 80×8 μm (B-1) and 50×5 μm (B-2).

(1) The age of this specimen was only 6 days. There were two cracks that were shown in Fig. 8. Crack B-1 was near a big aggregate. It was a little broad with some microcracks dispersed around it (Fig. 9). Crack B-2 was inside the mortar (Fig. 13).

(2) In Fig. 14, both Crack B-1 and Crack B-2 closed up a lot after 4 days biaxial load just like the aforementioned Crack A although there were some trails left (see details in Fig. 10 and Fig. 15 for Crack B-1 and Crack B-2, respectively).

(3) Forty days later with the biaxial load, Cracks B-1 and B-2 tended to fade out. There were some trails around the

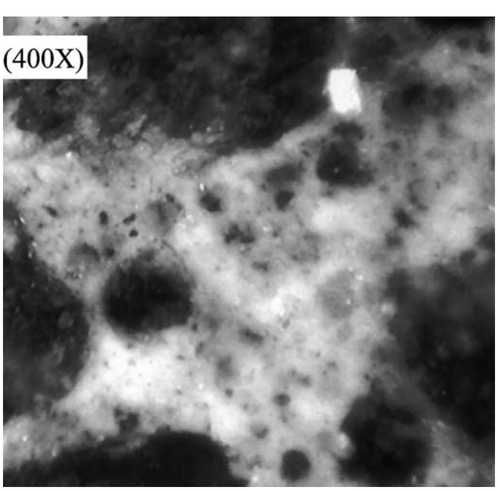

Fig. 6. Biaxial load for 14 days at the age of 10 days.

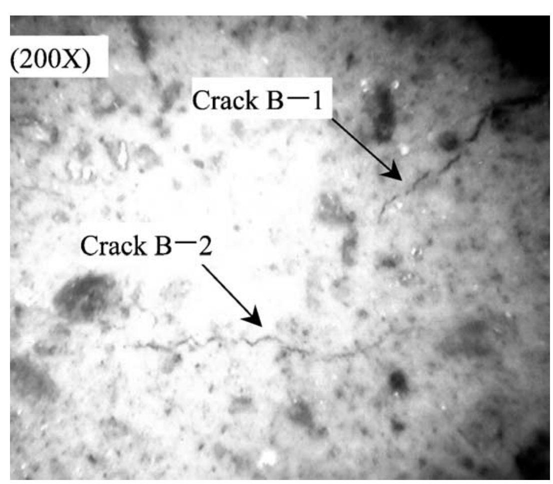

Fig. 8. Position of Crack B at the age of 6 days.

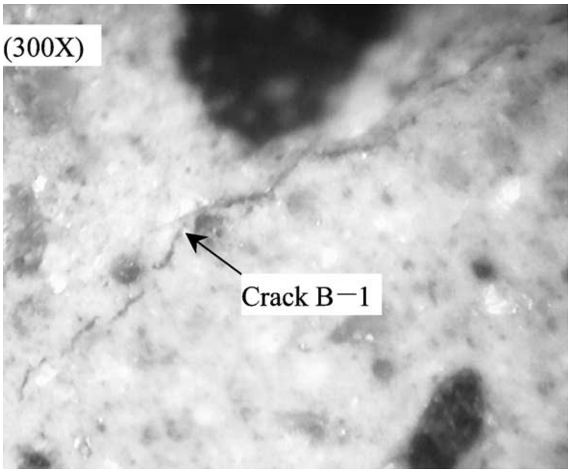

Fig. 9. Original crack when loaded at the age of 6 days.

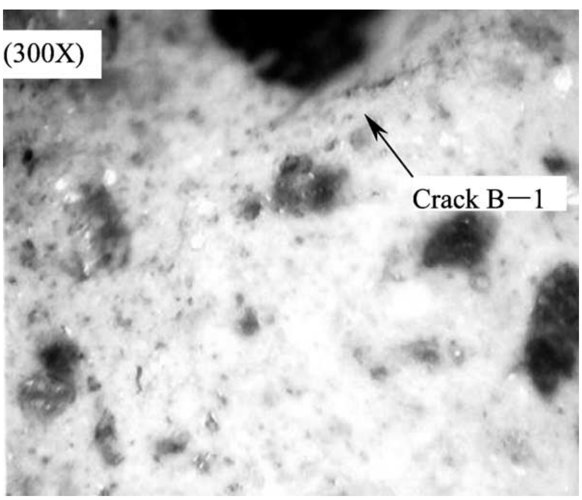

Fig. 10. Biaxial load for 4 days at the age of 6 days.

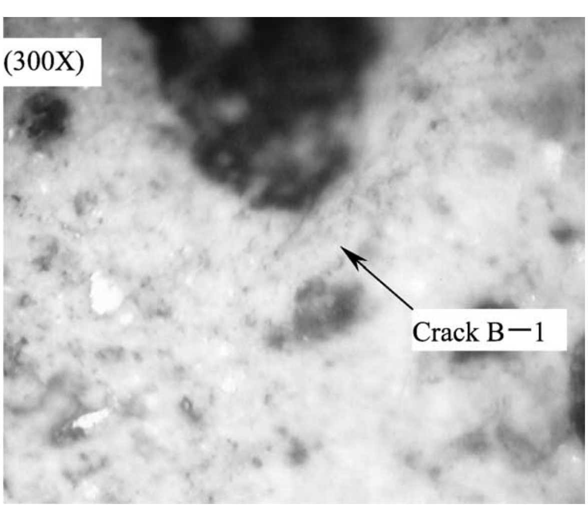

Fig. 11. Biaxial load for 40 days at the age of 6 days.

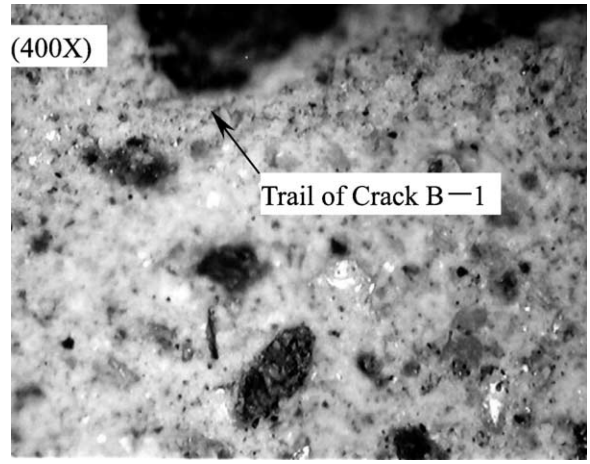

Fig. 12. Biaxial load for 100 days then unload for 8 days.

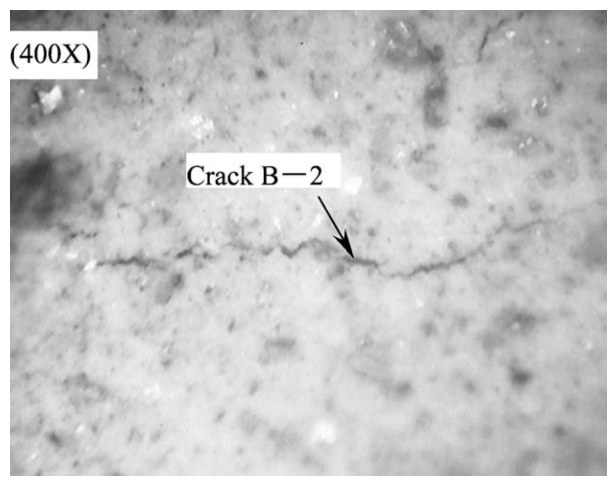

Fig. 13. Original crack when loaded at the age of 6 days.

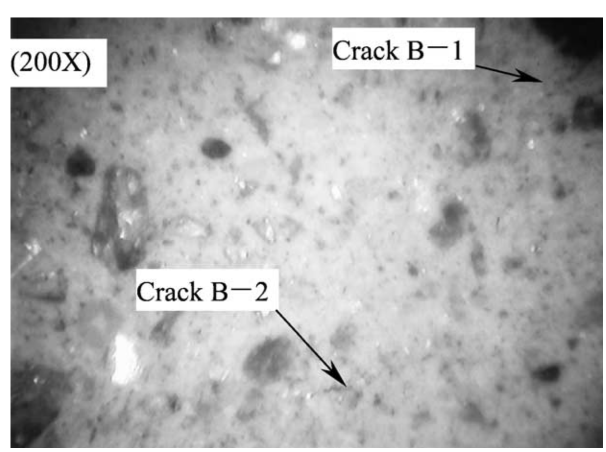

Fig. 14. Biaxial load for 4 days at the age of 6 days.

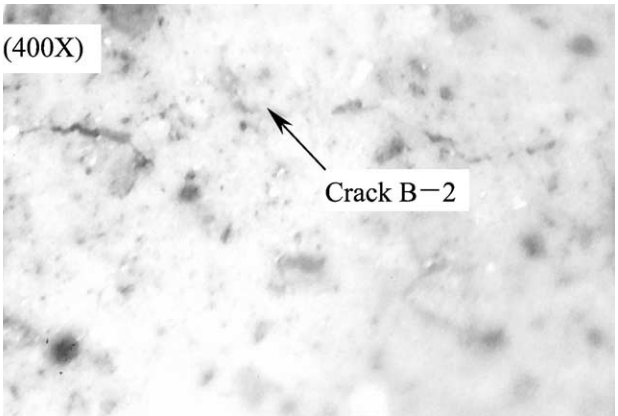

Fig. 15. Biaxial load for 4 days after the age of 6 days.

aggregate left for B-1 (Fig. 11). Crack B-2 disappeared totally in the mortar (Fig. 16). A hundred days later, the cracks were very blurry (Figs. 12 and 17).

3. Analysis

There were two types of cracks presented by Cracks A and B in the mortar and around the surface of the aggregate. Evidently, the aforementioned tests show that with time, the two types of cracks tend to disappear under the biaxial compression load especially in the mortar. For example, the lower part of Crack A faded out entirely even with no trails left. The interface crack closed obviously at the beginning though by a smaller degree compared with those inside the cement part. However, if the load lasted for more than 14 days, the interface crack also nearly disappeared.

When concrete was loaded at an early age, the cement part had not hydrated entirely. Also, the mechanical properties such as the strength of the cement-based material changed with the increase of the age. Different load conditions also influence the properties of the cement-based

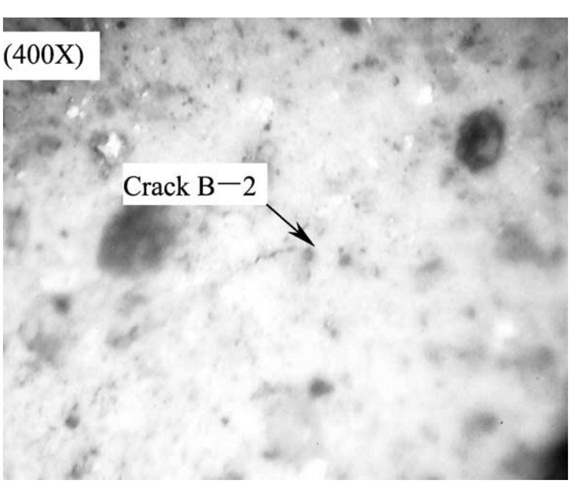

Fig. 16. Biaxial load for 40 days at the age of 6 days.

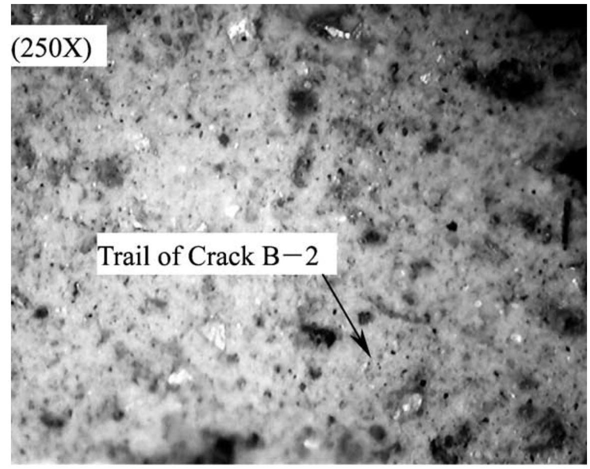

Fig. 17. Biaxial load for 100 days then unload 8 days.

specimens due to hydration. When subjected to the sustained biaxial compression, the cracks at the surface of the cement-based material like concrete tend to close up. Combined with the strength tests of the creep specimens (see Table 2), it is not so consistent with the common idea of "creep is one of the reason causing the damage of the concrete" [5]. Concrete creep deformations will not definitely cause damage of the material. On the contrary, the sustained compression load at an early age can increase the strength of the cement-based material which is different from that of the other materials [6]. Hydration products may come close more easily under the moderate biaxial compression loads especially at the early age. Moreover, the cracks could close if they are subject to an outer sustained compression load. Since the hydrated grains around the cracks will come closer with time if the humidity is appropriate, new or further hydration could take place. It could be easily found from the changes of Cracks A and B. When the specimen was unloaded and then reloaded, the cracks, especially those inside the mortar, did not open again at the former place. Those are very important in mass concrete like the dams.

Table 2
Creep specimen strength results

No.	Creep type	Load age (days)	Load duration (days)	Strength of creep specimen (MPa)	Strength of noncreep specimen (MPa)
A-1	Biaxial	14	45	–	8.2
A-2	Biaxial	60	90	14.4	11.3
B-1	Biaxial	30	28	10.8	5.5
B-2	Biaxial	60	30	10.7	7.0
C-1	Uniaxial	60	12	19.7	18.3
C-2	High stress uniaxial	90	18	19.8	20.9

All the stress levels were 30% of the ultimate strength except C-2 (60%).
There were three noncreep specimens in every group.
The values of the last column are the average strengths of the three noncreep specimens with the same ages of the corresponding creep specimens.

4. Strength results of preloaded specimens

Both uniaxial and biaxial creep machines were applied in the creep tests. The specimens were $100 \times 100 \times 100$ mm. They were unloaded after a certain period of sustained loading (more than 3 weeks). Then they were subjected to strength tests of which the results are shown in the following table. The noncreep specimen strengths are also listed for comparison.

As shown in the table, those creep specimens which were subjected to a sustained load at an early age (30 days) have higher strengths than those specimens with no sustained loading at the same age (e.g., B-1). When the age of creep loading is higher (60 days), the increase of the strengths is a little smaller (e.g., A-2 and B-2). When the concrete is older (90 days), this phenomenon will then weaken.

5. Conclusions

The long distance optical microscope with variable focus and high magnification can reveal new physical phenomena of the concrete hydration process. They connect the relation between the microchanges in concrete with the macromechanical properties such as the strength of the concrete.

The micro-observations indicate that cracks inside the concrete under biaxial sustained loads will fade out. Combined with the strength tests of the creep specimens, it is shown that biaxial compression load would help the cement-based material at an early age to compact the whole cement gel framework and to promote the hydration. It also formed the new cementation, which led to the restoration of the crack. Those deformations caused by compression creep at an early age will not always induce damage to the cement-based materials.

Acknowledgements

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